Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 184 SEPTEMBER, 1917 No. 3

# RADIATION AND THE ELECTRON.*

BY

R. A. MILLIKAN, Ph.D., Sc.D.,
Professor of Physics, University of Chicago.

RECENT developments in the domain of radiation are of extraordinary interest and suggestiveness, but they lead into regions in which the physicist sees as yet but dimly—indeed, even more dimly than he thought he saw twenty years ago.

But while the beauty of a problem solved excites the admiration and yields a certain sort of satisfaction, it is after all the unsolved problem, the quest of the unknown, the struggle for the unattained, which is of most universal and most thrilling interest. I make no apologies, therefore, for presenting to-night one of the great unsolved problems of modern physics, nor for leaving it with but the vaguest of suggestions toward a solution.

The newest of the problems of physics is at the same time the oldest. For nothing is earlier in the experiences either of the child or of the race than the sensation of receiving light and heat from the sun. But how does light get to us from the sun and the stars through the empty interstellar spaces? The Greeks answered this query very simply and very satisfactorily from the standpoint of people who were content with plausible explanations but had not yet learned perpetually to question nature experimentally as to the validity or invalidity of a con-

*Presented at the meeting of the Section of Physics and Chemistry held Thursday, January 4, 1917.

[NOTE.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.]
Copyright, 1917, by THE FRANKLIN INSTITUTE.

clusion. They said that the sun and all radiators of light and heat must shoot off minute corpuscles whose impact upon the eye or skin produces the sensations of light and warmth.

This corpuscular theory was the generally accepted one up to 1800 A.D. It was challenged, it is true, about 1680 by the Dutch physicist Huygens, who, starting with the observed phenomena of the transmission of water waves over the surface of a pond or of sound waves through the air, argued that light might be some vibratory disturbance transmitted by some medium which fills all interstellar space. He postulated the existence of such a medium, which was called the luminiferous or light-bearing ether.

Partly no doubt because of Newton's espousal of the corpuscular theory, the ether or wave theory gained few adherents until some facts of interference began to appear about 1800 which baffled explanation from the standpoint of the corpuscular theory, but which were easily handled by its rival. During the nineteenth century the evidence became stronger and stronger, until by its close the corpuscular theory had been permanently eliminated for four different reasons: (1) The facts of interference were not only found inexplicable in terms of it, but they were completely predicted by the wave theory. (2) The fact that the speed of propagation of light was experimentally found to be greater in air than in water was in accord with the demands of the ether theory, but directly contrary to the demands of the wave theory. (3) Wireless waves had appeared and had been shown to be just like light waves save for wave-length, and they had been found to pass over continuously, with increasing wave-length, into static electrical fields such as could not possibly be explained from a corpuscular point of view. (4) The speed of light had been shown to be independent of the speed of the source as demanded by the ether theory and denied by the corpuscular theory.

By 1900, then, the ether theory had become apparently impregnably intrenched. A couple of years later it met with some opposition of a rather ill-considered sort, as it seems to me, from a group of extreme advocates of the relativity theory, but this theory is now commonly regarded, I think, as having no bearing whatever upon the question of the existence or non-existence of a luminiferous ether. For such an ether was called

into being solely for the sake of furnishing a carrier for electromagnetic waves, and it obviously stands or falls with the existence of such waves *in vacuo*, and this has never been questioned by anyone so far as I am aware.

Up to 1903, then, the theory which looked upon an electromagnetic wave as a disturbance which originated at some point in the ether at which an electric charge was undergoing a change in speed, and was propagated from that point outward as a spherical wave or pulse, the total energy of the disturbance being always spread uniformly over the wave front, had met with no serious question from any source. Indeed, it had been extraordinarily successful, not only in accounting for all the known facts, but in more than one instance in predicting new ones. The first difficulty appeared after the discovery of the electron and in connection with the relations of the electron to the absorption or emission of such electromagnetic waves. It was first pointed out in 1903 by Sir J. J. Thomson in his Silliman lectures at Yale. It may be stated thus:

X-rays unquestionably pass over, or past, all but an exceedingly minute fraction, say one in a thousand billion, of the atoms contained in the space traversed without spending any energy upon them or influencing them in any observable way. But here and there they find an atom from which, as is shown directly in C. T. R. Wilson's photographs here presented on the screen, they hurl a negative electron with enormous speed. This is the most interesting and most significant characteristic of X-rays, and one which distinguishes them from the $\alpha$- and $\beta$-rays just as sharply as does the property of non-deviability in a magnetic field; for neither $\alpha$- nor $\beta$-rays ever eject electrons from the atoms through which they pass with speeds comparable with those produced by X-rays, else there would be new zigzag lines branching out from points all along the paths of the $\alpha$- and $\beta$-particles shown in the Wilson photographs.

But this property of X-rays introduces a serious difficulty into the ether theory. For if the electric intensity in the wave front of the X-ray is sufficient thus to hurl a corpuscle with huge energy from one particular atom, why does it not at least detach corpuscles from all of the atoms over which it passes?

Again when ultra-violet light falls on a metal it, too, like X-rays is found to eject negative electrons. This phenomenon

of the emission of corpuscles under the influence of light is called the photo-electric effect. Lenard [1] first made the astonishing discovery that the energy of ejection of the corpuscle is altogether independent of the intensity of the light which causes the ejection, no matter whether this intensity is varied by varying the distance of the light or by introducing absorbing screens. I have myself [2] subjected this relation to a very precise test and found it to hold accurately. Furthermore, this sort of independence has also been established for the negative electrons emitted by both X- and $\gamma$-rays.

Facts of this sort are evidently difficult to account for on any sort of a spreading-wave theory. But it will be seen that they lend themselves to easy interpretation in terms of a corpuscular theory, for if the energy of an escaping electron comes from the absorption of a light-corpuscle, then the energy of emission of the ejected electron ought to be independent of the distance of the source, as it is found to be, and furthermore, corpuscular rays would hit but a very minute fraction of the atoms contained in the space traversed by them. This would explain, then, both the independence of the energy of emission upon intensity and the smallness of the number of atoms ionized.

In view, however, of the four sets of facts mentioned above, Thomson found it altogether impossible to go back to the old and exploded form of corpuscular theory for an explanation of the new facts as to the emission of electrons under the influence of ether waves. He accordingly attempted to reconcile these troublesome new facts with the wave theory by assuming a fibrous structure in the ether and picturing all electromagnetic energy as traveling along Faraday lines of force conceived of as actual strings extending through all space. Although this concept, which we shall call the ether-string theory, is like the corpuscular theory in that the energy, after it leaves the emitting body, remains localized in space, and, when absorbed, is absorbed as a whole, yet it is after all essentially an ether theory. For in it the speed of propagation is determined by the properties of the medium and has nothing to do with the nature or condition of the source. Thus the last three of the fatal objections to a corpuscular theory are not here encountered. As to

[1] *Ann. d. Phys.* (4), viii (1902), 149.
[2] *Phys. Rev.*, ii (1913), 173.

the first one, no one has yet shown that Thomson's suggestion is reconcilable with the facts of interference, though so far as I know, neither has its irreconcilability been as yet absolutely demonstrated.

But interference aside, all is not simple and easy for Thomson's theory. For one encounters serious difficulties when he attempts to visualize the universe as an infinite cobweb whose threads never become tangled or broken however swiftly the electrical charges to which they are attached may be flying about.

Yet the boldness and the difficulties of Thomson's "ether-string" theory did not deter Einstein[3] in 1905 from making it even more radical. In order to connect up with some results to which Planck, of Berlin, had been led in studying the facts of black-body radiation, Einstein assumed that the energy emitted by any radiator not only kept together in bunches or quanta as it traveled through space, as Thomson had assumed it to do, but that a given source could emit and absorb radiant energy only in units which are all exactly equal to $h\nu$, $\nu$ being the natural frequency of the emitter and $h$ a constant which is the same for all emitters.

I shall not attempt to present the basis for such an assumption, for, as a matter of fact, it had almost none at the time. But whatever its basis, it enabled Einstein to predict at once that the energy of emission of corpuscles under the influence of light would be governed by the equation

$$\tfrac{1}{2}mv^2 = Ve = h\nu - p \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (41)$$

in which $h\nu$ is the energy absorbed by the electron from the light wave or light quantum, for according to the assumption it was the whole energy contained in that quantum, $p$ is the work necessary to get the electron out of the metal, and $\tfrac{1}{2}mv^2$ is the energy with which it leaves the surface—an energy evidently measured by the product of its charge $e$ by the potential difference $V$ against which it is just able to drive itself before being brought to rest.

At the time at which it was made this prediction was as bold as the hypothesis which suggested it, for at that time there were available no experiments whatever for determining anything about how the positive potential $V$ necessary to apply to the

[3] *Ann. d. Phys.* (4), xvii (1905), 132; xx (1906), 199.

illuminated electrode to stop the discharge of negative electrons from it under the influence of monochromatic light varied with the frequency $\nu$ of the light, or whether the quantity $h$ to which Planck had already assigned a numerical value appeared at all in connection with photo-electric discharge. We are confronted, however, by the astonishing situation that after ten years of work at the Ryerson Laboratory and elsewhere in the discharge of elec-

FIG. 1.

Photograph of apparatus used for the photo-electric determination of Planck's $h$.

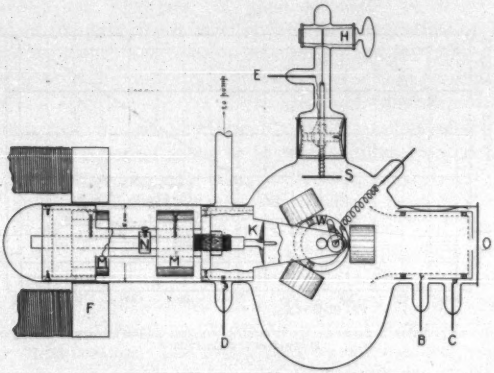
trons by light this equation of Einstein's seems to us to predict accurately all of the facts which have been observed.

The method which has been adopted in the Ryerson Laboratory for testing the correctness of Einstein's equation has involved the performance of so many operations upon the highly inflammable alkali metals in a vessel which was freed from the presence of all gases that it is not inappropriate to describe the present experimental arrangement as a machine-shop *in vacuo*. Fig. 1 shows a photograph of the apparatus, and Fig. 2 is a

drawing of a section which should make the necessary operations intelligible.

One of the most vital assertions made in Einstein's theory is that the kinetic energy with which monochromatic light ejects electrons from any metal is proportional to the frequency of the light, *i.e.*, if violet light is of half the wave-length of red light, then the violet light should throw out the electron with twice the energy imparted to it by the red light. In order to test whether any such linear relation exists between the energy of the escaping electron and the light which throws it out it

FIG. 2.

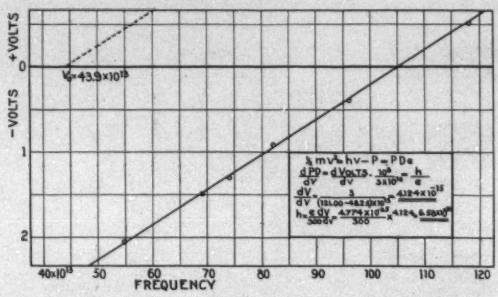



Cross-sectional drawing of apparatus of Fig. 1.

was necessary to use as wide a range of frequencies as possible. This made it necessary to use the alkali metals, sodium potassium, and lithium, for electrons are thrown from the ordinary metals only by ultra-violet light, while the alkali metals respond in this way to any waves shorter than those of the red, that is, they respond throughout practically the whole visible spectrum as well as the ultra-violet spectrum. Cast cylinders of these metals were therefore placed on the wheel *W* (Fig. 2) and fresh clean surfaces were obtained by cutting shavings from each metal in an excellent vacuum with the aid of the knife *K*, which was operated by an electromagnet *F* outside the tube. After this the

freshly cut surface was turned around by another electromagnet until it was opposite the point $O$ of Fig. 2 and a beam of monochromatic light from a spectrometer was let in through $O$ and allowed to fall on the new surface. The energy of the electrons ejected by it was measured by applying to the surface a positive potential just strong enough to prevent any of the discharged electrons from reaching the gauze cylinder opposite (shown in dotted lines) and thus communicating an observable negative charge to the quadrant electrometer which was attached to this gauze cylinder. For a complete test of the equation it was necessary also to measure the contact-electromotive force between

FIG. 3.




Graph showing relation between energy of electric emission and frequency of the light which stimulates the emission.

the new surface and a test plate $S$. This was done by another electromagnetic device shown in Fig. 1, but for further details the original paper may be consulted.[4] Suffice it here to say that Einstein's equation demands a linear relation between the applied positive volts and the frequency of the light, and it also demands that the slope of this line should be exactly equal to $\frac{h}{e}$. Hence from this slope, since $e$ is known, it be possible to obtain $h$. How perfect a linear relation is found may be seen from Fig. 3, which also shows that from the slope of this line $h$ is found to be $6.26 \times 10^{-27}$, which is as close to the value obtained by Planck from the radiation laws as is to be expected from the accuracy

[4] *Phys. Rev.*, vii (1916), 362.

with which the experiments in radiation can be made. The most reliable value of $h$ obtained from a consideration of the whole of this work is

$$h = 6.56 \times 10^{-27}.$$

In the original paper will be found other tests of the Einstein equation, but the net result of all this work is to confirm in a very complete way the equation which Einstein first set up on the basis of his semi-corpuscular theory of radiant energy. And if this equation is of general validity it must certainly be regarded as one of the most fundamental and far-reaching of the equations of physics, and one which is destined to play in the future a scarcely less important rôle than Maxwell's equations have played in the past, for it must govern the transformation of all short-wave-length electromagnetic energy into heat energy.

In spite of the credentials which have just been presented for Einstein's equation, we are confronted with the extraordinary situation that the semi-corpuscular theory out of which Einstein got his equation seems to be wholly untenable and has in fact been pretty generally abandoned, though Sir J. J. Thomson [5] and a few others [6] seem still to adhere to some form of ether-string theory, that is, to some form of theory in which the energy remains localized in space instead of spreading over the entire wave front.

Two very potent objections, however, may be urged against all forms of ether-string theory of which Einstein's is a particular modification. The first is that no one has ever yet been able to show that such a theory can predict any one of the facts of interference. The second is that there is direct positive evidence against the view that the ether possesses a fibrous structure. For if a static electrical field has a fibrous structure, as postulated by any form of ether-string theory, "each unit of positive electricity being the origin and each unit of negative electricity the termination of a Faraday tube," [7] then the force acting on one single electron between the plates of an air condenser cannot possibly vary *continuously* with the potential difference

[5] *Proc. Phys. Soc. of London*, xxvii (December 15, 1914), 105.
[6] "Modern Electrical Theory," Cambridge, University Press, 1913, p. 248.
[7] J. J. Thomson, "Electricity and Matter," p. 9.

between the plates. Now in the oil-drop experiments [8] we actually study the behavior in such an electric field of one single, isolated electron and we find, over the widest limits, exact proportionality between the field strength and the force acting on the electron as measured by the velocity with which the oil drop to which it is attached is dragged through the air.

When we maintain the field constant and vary the charge on the drop, the granular structure of electricity is proved by the discontinuous changes in the velocity, but when we maintain the charge constant and vary the field the lack of discontinuous change in the velocity disproves the contention of a fibrous structure in the field, unless the assumption be made that there are an enormous number of ether strings ending in one electron. Such an assumption takes all the virtue out of an ether-string theory.

Despite then the apparently complete success of the Einstein equation, the physical theory of which it was designed to be the symbolic expression is found so untenable that Einstein himself, I believe, no longer holds to it, and we are in the position of having built a very perfect structure and then knocked out entirely the underpinning without causing the building to fall. It stands complete and apparently well tested, but without any visible means of support. These supports must obviously exist, and the most fascinating problem of modern physics is to find them. Experiment has outrun theory, or, better, guided by erroneous theory, it has discovered relationships which seem to be of the greatest interest and importance, but the reasons for them are as yet not at all understood.

It is possible, however, to go a certain distance toward a solution and to indicate some conditions which must be satisfied by the solution when it is found. For the energy $h\nu$ with which the electron is found by experiment to escape from the atom must have come either from the energy stored up inside of the atom or else from the light. There is no third possibility. Now the fact that the energy of emission is the same, whether the body from which it is emitted is held within an inch of the source, where the light is very intense, or a mile away, where it is very weak, would seem to indicate that the light simply pulls a trigger in the atom which itself furnishes all the energy with which the electron escapes, as was originally suggested by Len-

[8] *Phys. Rev.*, ii (1913), 109.

ard in 1902,[9] or else, if the light furnishes the energy, that light itself must consist of bundles of energy which keep together as they travel through space, as suggested in the Thomson-Einstein theory.

Yet the fact that the energy of emission is directly proportional to the frequency $\nu$ of the incident light spoils Lenard's form of trigger theory, since, if the atom furnishes the energy, it ought to make no difference what kind of a wave-length pulls the trigger, while it ought to make a difference what kind of a gun, that is, what kind of an atom, is shot off. But both of these expectations are the exact opposite of the observed facts. *The energy of the escaping corpuscle must come then, in some way or other, from the incident light.*

When, however, we attempt to compute on the basis of a spreading-wave theory how much energy a corpuscle can receive from a given source of light, we find it difficult to find anything more than a very minute fraction of the amount which the corpuscle actually acquires.

Thus, the total luminous energy falling per second from a standard candle on a square centimeter at a distance of 3 m. is 1 erg.[10] Hence the amount falling per second on a body of the size of an atom, *i.e.*, of cross-section $10^{-15}$ cm., is $10^{-15}$ ergs, but the energy $h\nu$ with which a corpuscle is ejected by light of wave-length 500 $\mu\mu$ (millionths millimeter) is $4 \times 10^{-12}$ ergs, or 4,000 times as much. Since not a third of the incident energy is in wave-lengths shorter than 500 $\mu\mu$, a surface of sodium or lithium which is sensitive up to 500 $\mu\mu$ should require, even if all this energy were in one wave-length, which it is not, at least 12,000 seconds or 4 hours of illumination by a candle 3 m. away before any of its atoms could have received, all told, enough energy to discharge a corpuscle. Yet the corpuscle is observed to shoot out the instant the light is turned on. It is true that Lord Rayleigh has recently shown [11] that an atom may conceivably absorb wave-energy from a region of the order of magnitude of the square of a wave-length of the incident light rather than of the order of its own cross-section. This in no way weakens, however, the cogency of the type of argument just presented, for it is only

[9] *Ann. d. Phys.* (4), viii (1902), 149.
[10] Drude, "Lehrbuch der Optik," 1906, p. 472.
[11] *Phil. Mag.*, xxxii (1916), 188.

necessary to apply the same sort of analysis to the case of $\gamma$-rays, the wave-length of which is of the order of magnitude of an atomic diameter ($10^{-8}$ cm.) and the difficulty is found still more pronounced. Thus Rutherford[12] estimates that the total $\gamma$-ray energy radiated per second by one gramme of radium cannot possibly be more than $4.7 \times 10^4$ ergs. Hence at a distance of 100 meters, where the $\gamma$-rays from a gramme of radium would be easily detectable, the total $\gamma$-ray energy falling per second on a square millimeter of surface, the area of which is ten-thousand billion times greater than that either of an atom or of a disk whose radius is a wave-length, would be $4.7 \times 10^4 \div 4\pi \times 10^{10} = 4 \times 10^{-7}$ ergs. This is very close to the energy with which $\beta$-rays are actually observed to be ejected by these $\gamma$-rays, the velocity of ejection being about nine-tenths that of light. Although, then, it should take ten thousand billion seconds for the atom to gather in this much energy from the $\gamma$-rays, on the basis of classical theory, the $\beta$-ray is observed to be ejected with this energy as soon as the radium is put in place. This shows that if we are going to abandon the Thomson-Einstein hypothesis of localized energy, which is, of course, competent to satisfy these energy relations, there is no alternative but to assume that at some previous time the corpuscle had absorbed and stored up from light of this or other wave-length enough energy so that it needed but a minute addition at the time of the experiment to be able to be ejected from the atom with the energy $h\nu$.

Now the corpuscle which is thus ejected by the light cannot possibly be one of the free corpuscles of the metal, for such a corpuscle, when set in motion within a metal, constitutes an electric current, and we know that such a current at once dissipates its energy into heat. In other words, a *free* corpuscle can have no mechanism for storing up energy and then *jerking* itself up "by its boot straps" until it has the huge speed of emission observed.

The ejected corpuscle must then have come *from the inside of the atom*, in which case it is necessary to assume, if the Thomson-Einstein theory is rejected, that within the atom there exists some mechanism which will permit a corpuscle continually to absorb and load itself up with energy of a given frequency until a value at least as large as $h\nu$ is reached. What sort of a

[12] "Radioactive Substances and their Radiations," p. 288.

mechanism this is we have at present no idea. Further, if the absorption is due to resonance—and we have as yet no other way in which to conceive it—it is difficult to see how there can be, in the atoms of a solid body, corpuscles having all kinds of natural frequencies so that some are always found to absorb and ultimately be rejected by impressed light of any particular frequency. But apart from these difficulties, the thing itself is impossible if these absorbing corpuscles, when not exposed to radiation, are emitting any energy at all; for if they did so, they would in time lose all their store and we should be able, by keeping bodies in the dark, to put them into a condition in which they should show no emission of corpuscles whatever until after hours or years of illumination with a given wave-length. Since this is contrary to experiment, we are forced, even when we discard the Thomson-Einstein theory of localized energy, to postulate electronic absorbers which, during the process of absorbing, do not radiate at all until the absorbed energy has reached a certain critical value when explosive emission occurs.

However, then, we may interpret the phenomenon of the emission of corpuscles under the influence of ether waves, whether upon the basis of the Thomson-Einstein assumption of bundles of localized energy traveling through the ether, or upon the basis of a peculiar property of the inside of an atom which enables it to absorb continuously incident energy and emit only explosively, *the observed characteristics of the effect seem to furnish proof that the emission of energy by an atom is a discontinuous or explosive process.* This was the fundamental assumption of Planck's so-called quantum theory of radiation. The Thomson-Einstein theory makes both the absorption and the emission sudden or explosive, while the loading theory, first suggested by Planck, though from another view-point, makes the absorption continuous and only the emission explosive.

The $h$ determined above with not more than one-half of 1 per cent. of uncertainty is the explosive constant, *i.e.*, it is the unchanging ratio between the energy of emission and the frequency of the incident light. It is a constant the existence of which was first discovered by Planck by an analysis of the facts of black-body radiation, though the physical assumptions underlying Planck's analysis do not seem to be longer tenable. For the American physicists Duane and Hunt[13] and Hull[14] have

[13] *Phys. Rev.*, vi (1915), 166.

[14] *Ibid.*, vii (1916), 157.

recently shown that the same quantity $h$ appears in connection with the impact of corpuscles against any kind of a target, the observation here being that the highest frequency in the general or white-light X-radiation emitted when corpuscles impinge upon a target is found by dividing the kinetic energy of the impinging corpuscle by $h$. Since black-body radiation is presumably due to the impact of the *free* corpuscles within a metal upon the atoms, it is probable that the appearance of $h$ in black-body radiation and in general X-radiation is due to the same cause, so that, contrary to Planck's assumption, there need not be, in either of these cases, any coincidence between natural and impressed periods at all. The $h\nu$ which here appears is not a characteristic of the atom, but merely a property of the ether pulse which is generated by the stopping of a moving electron. Why this ether pulse should be resolvable into a continuous, or white-light spectrum which, however, has the peculiar property of being chopped off sharply at a particular limiting frequency given by $h\nu = PD \times e$ is thus far a complete mystery. All that we can say is that experiment seems to demand a sufficient modification of the ether-pulse theory of white-light and of general X-radiation to take this experimental fact into account.

On the other hand, the appearance of $h$ in connection with the absorption and emission of *monochromatic* light (photo-electric effect and Bohr atom) seem to demand some hitherto unknown type of absorbing and emitting mechanism within the atom. This demand is strikingly emphasized by the remarkable absorbing property of matter for X-rays, discovered by Barkla[15] and beautifully exhibited in De Broglie's photographs here shown.[16] It will be seen from these photographs that *the atoms of each particular substance transmit the general X-radiation up to a certain critical frequency and then absorb all radiations of higher frequency than this critical value.* The extraordinary significance of this discovery lies in the fact that it indicates that there is a type of absorption which is not due either to resonance or to free electrons. But these are the only types of absorption which are recognized in the structure of modern optics. We

[15] *Phil. Mag.*, xvii (1909), 749.

[16] These photographs will be found also in the August number of the *Physical Review* (see Presidential address of the President of the Physical Society).

have as yet no way of conceiving of this new type of absorption in terms of a mechanical model.

There is one result, however, which seems to be definitely established by all of this experimental work. Whether the radiation is produced by the stopping of a free electron as in Duane and Hunt's experiment, and presumably also in black-body experiments or by the absorption and re-emission of energy by bound electrons, as in photo-electric and spectroscopic work, Planck's $h$ seems to be always tied up in some way with the emission and absorption of energy by the electron. *$h$ may, therefore, be considered as one of the properties of the electron.*

The new facts in the field of radiation which have been discovered through the study of the properties of the electron seem, then, to require in any case a very fundamental revision or extension of classical theories of absorption and emission of radiant energy. The Thomson-Einstein theory throws the whole burden of accounting for the new facts upon the unknown nature of the ether and makes radical assumptions about its structure. The loading theory leaves the ether as it was and puts the burden of an explanation upon the unknown conditions and laws which exist inside the atom. I have already given reasons for discrediting the first type of theory. The second type, though as yet very incomplete, seems to me to be the only possible one, and it has already met with some notable successes, as in the case of the Bohr atom. Yet the theory is at present woefully incomplete and hazy. About all that we can say now is that we seem to be driven by newly discovered relations in the field of radiation either to the Thomson-Einstein semi-corpuscular theory, or else to a theory which is equally subversive of the established order of things in physics. For either one of these alternatives brings us to a very revolutionary quantum theory of radiation, that is, a theory which calls for an explosive emission of energy in units and which therefore has something akin to atomism about it. To be living in a period which faces such a complete reconstruction of our notions as to the way in which ether waves are absorbed and emitted by matter is an inspiring prospect. The atomic and electronic worlds have revealed themselves with beautiful definiteness and wonderful consistency to the eye of the modern physicist, but their relation to the world of ether waves is still to him a profound mystery for which the coming generation has the incomparable opportunity of finding a solution.

**The Grinding Wheel.** R. G. WILLIAMS. (*Proceedings of the American Electrochemical Society*, May 2–5, 1917.)—The success of the modern grinding wheel is dependent to a very large degree upon the product of the electric furnace (namely, artificial abrasives), these having almost entirely supplanted the formerly widely used emery. Artificial abrasives are of two kinds or groups—the aluminous group and the carbide of silicon group. The first contains aluminum oxide as the main constituent, and the different materials which it forms vary quite widely in physical properties, according to their chemical composition and electric furnace treatment. The carbide of silicon abrasives, forming the second group, vary but slightly in chemical composition and physical properties.

The crude abrasive is delivered from the electric furnace to the grinding-wheel factory, and broken up into lumps which will pass through a six-inch ring and smaller. The first step in the production of grain to be used in grinding wheels and other products such as oilstones, rubbing bricks, refractories, and so forth, is to pass the material through powerful crushers equipped with manganese steel jaws. This operation reduces the material to small lumps. It is further reduced from small lumps to grains by passing through a series of rolls, each pair being set to crush smaller than the preceding. In this way a range of sizes from very coarse to very fine is produced. Some abrasives contain an appreciable amount of magnetic material detrimental to the manufacture of wheels. This is removed by means of a magnetic separator. The material is further freed from extraneous matter by a washing process. The material is then sized by passing through screens of varying mesh, and, for the very fine sizes referred to as "flour," by a sedimentation process.

All grinding wheels are composed of two main constituents—the abrasive and the bond, or the substance by which the particles of abrasive are held together. The commercial method of classifying grinding wheels is by the kind of bonding material used. The most widely used type of wheel is that bonded by a ceramic process in which the mixture of abrasive and a clay bond are baked in a kiln like pottery ware. Such wheels are known as *vitrified wheels*. Another type of bonding where elasticity is sought is represented by *vulcanized wheels*. Here, as indicated by the name, the bonding material is vulcanized rubber. The operation of vulcanizing the mixture of abrasive rubber and sulphur is similar to that employed in vulcanizing any other product. The wheels, which have been moulded approximately to size, are finally provided with a lead centre and trued to size with a diamond tool.

# THE CHEMISTRY OF CELLULOSE AND ITS IMPORTANT INDUSTRIAL APPLICATIONS.*

BY

**H. S. MORK, B.S.,**

Arthur D. Little, Incorporated, Boston, Mass.

THE mere mention of the word "Cellulose" conveys to the average person very little meaning or significance, and yet cellulose, in one form or another, is just as essential to the convenience and comfort of modern humanity as are iron, copper, glass, and materials of this general type with which everybody is familiar. Cellulose may be defined as the material of which the cell walls of plants are composed, and consequently it is easy to appreciate the abundance of this substance in nature, and its wide dissemination over the face of the earth. Cellulose is a true carbohydrate, and in its simplest form is familiar to everybody in the shape of cotton, linen, or wood-pulp. Clean cotton is practically pure cellulose, but most cellulose in nature is in a compound form—lignocellulose—in which the cellulose is more or less strongly combined with lignin. From such lignocellulose it is not a matter of great difficulty, by digesting or cooking with proper chemicals, to isolate the cellulose. On this, of course, are based the wood-pulp and paper industries.

It is not the purpose of this lecture to go into intimate discussion of the absolute chemical composition of cellulose, or to consider from a theoretical point of view the chemistry of the various known reactions, but rather to deal with technical cellulose chemistry broadly, and perhaps bring out some points which are of interest to the user of cellulose products.

To date the true chemical structure of cellulose is not known. Several formulæ have been suggested, but they are all matters of speculation, because there are not sufficient data on which to base any definite structural formula. As has been stated, cellulose is a carbohydrate of the empirical formula $C_6H_{10}O_5$, but the cellulose molecule is very complex and made up of a large aggregate of groups of the composition designated by this formula. On

* Presented at the meeting of the Section of Physics and Chemistry, held Thursday, March 29, 1917.

account of the abundance of cellulose in nature, its synthesis offers very little inducement with the object of commercial substitution of an artificial cellulose, but there is no question that the ability to synthesize cellulose and the knowledge of its structural formula would be helpful both to pure science and to industrial applications of cellulose, for these reasons at least:

1. It would increase our knowledge of nature's processes.

2. It would afford a better comprehension of the known cellulose reactions, and would be helpful in the elucidation of their eccentricities, of which there are certainly plenty.

3. It would greatly increase the possibilities of new cellulose reactions, and in this connection it should be stated that practically every known reaction of cellulose has become the basis of important processes.

4. It would also give us a more precise knowledge of what takes place in the dyeing of cellulosic fibres, and there are probably other advantages to be gained.

### CELLULOSE SOLVENTS.

The solvents of cellulose—and in this connection do not confuse cellulose with cellulose compounds—are either very strongly acid or strongly alkaline in character. The discovery of a neutral solvent, the solution of cellulose in which could be readily coagulated by some other neutral chemical, or at the most a chemical only mildly acid or alkaline, or the discovery of a neutral volatile solvent, on the evaporation of which a cellulose film or deposit would be formed, would be discoveries of tremendous importance and value. The ordinary industrial solvents of cellulose which at the same time do not transform it into compounds other than those formed by the addition of water are strong sulphuric acid, zinc chloride or bromide, neutral or acid, and cuprammonium solution, which is a strong solution of copper hydrate or carbonate in ammonia. There are several other solvents, such as ammonium sulphocyanate, etc., but at the present time they are of no appreciable commercial importance.

Sulphuric acid finds its chief industrial application as a cellulose solvent in the manufacture of parchment paper, although a recent patent has been issued for the adaptation of a sulphuric acid solution of cellulose at very low temperatures to the manufacture of films and filaments. In the ordinary process for parch-

mentizing paper, the paper is run through a strong sulphuric acid bath, with the proper conditions of concentration, temperature, and speed, so that merely the surface of the paper is gelatinized, which on subsequent dilution and washing is coagulated and remains fixed on the surface of the paper, giving to the parchment paper its familiar grease-proof quality.

The chief applications of zinc chloride as a solvent are the manufacture of incandescent lamp filaments and the production of vulcanized fibre. In the former case, cellulose is dissolved in zinc chloride solution of high concentration, and this solution is squirted into the alcohol, whereby it coagulates into the filaments, which are washed free from chemicals and dried. In view of the rapid strides which the tungsten filament is making, this use of zinc chloride cellulose solution is gradually becoming less important.

In the production of vulcanized fibre, the process is somewhat similar to the sulphuric acid parchmentizing process, but in this case special absorbent paper is run through a strong zinc chloride solution, and the fibres are superficially gelatinized by means of the solvent. When thick sheets of vulcanized fibre are desired, thin gelatinized sheets are wound around a mandrel or drum to the desired thickness, and cement themselves together. In this process, as in the parchmentizing process, it is absolutely essential to eliminate all the zinc chloride or the sulphuric acid, because otherwise the products would disintegrate on storing, or else they would be deficient in desired properties.

A solution of cellulose in cuprammonium solution is the basis of one of the processes for the manufacture of artificial silk. This process has been extensively operated in Europe, but a few sporadic attempts to operate in this country have not met with success. The solvent power of cuprammonium for cellulose at one time was applied in England in the manufacture of Willesden goods.

### HYDROLYSIS AND HYDRATION.

When cellulose is dissolved and recovered from a solution by coagulation, the original fibrous structure is, naturally, always destroyed. In the coagulated products the cellulose is in a highly hydrated condition, and these products are various forms of hydrated cellulose. It is a matter of controversy whether a cellulose hydrate is cellulose in a form capable merely of mechan-

ically holding a large amount of water, or whether this water, in part at least, is chemically combined with the cellulose. Perhaps the burden of the evidence is in favor of mechanical absorption, and not the chemical combination; for it is true that when a cellulose jell or hydrate is once dried it does not then have the capacity of absorbing as much water as it mechanically held before drying.

Besides cellulose hydrates, there is another form or combination of water and cellulose, called "hydrocellulose." This is a real hydrolyzed form of cellulose, and is produced when acids and alkalies act on cellulose, with the proper conditions of time and temperature, and not necessarily with accompanying solution, because hydrocellulose may still preserve the form of the original fibre. In hydrolyzed cellulose the amount of water combined is variable, depending upon the severity of the hydrolysis, the ultimate result of continued hydrolysis being the formation of dextrose, similarly as in the formation of dextrose from starch. It is highly probable that the hydrolysis of cellulose proceeds along lines closely analogous to the hydrolysis of starch, and that between dextrose and sugar various dextrines are intermediately formed.

Industrially, the hydrolysis of cellulose is of great importance. It is the basis of the carbonization process for separating cotton from wool, in which, as you know, shoddy is immersed in a sulphuric or hydrochloric acid solution, and on drying, with the acid still in it, the cotton is converted into brittle hydrocellulose which is dusted out, leaving the wool behind. The production of hydrocellulose is also an intermediate step in the carrying out of some cellulose reactions; for example, in some of the processes of manufacturing cellulose acetate, hydrocellulose is first formed, and the esterification or formation of the acetate takes place afterwards. Also, in the viscose reaction—and of both of these reactions I will speak about later—the sustained action of the caustic soda on wood-pulp tends to break down the cellulose structure with accompanying hydrolysis. The complete hydrolysis of cellulose to sugar is assuming considerable industrial importance in the manufacture of ethyl alcohol from sawdust or other cellulosic wastes. This is an established process of demonstrated merit, and it is not unreasonable to predict that it will ultimately be the solution of the motor fuel problem, particularly if it can be adapted—and there seems to be no fundamental reason why

it cannot be—to the hydrolysis of wastes from perennial plant growths. Inasmuch as hydrocellulose is soluble in all the cellulose solvents, and can usually be recovered from these in the gelatinous condition, it can readily be seen that a hydrocellulose hydrate or a hydrated hydrocellulose is a possibility, and is in fact an actuality.

### OXIDATION.

Cellulose is susceptible to oxidation with the formation of oxycellulose, and the formation of a cellulose peroxide has been reported. Oxycellulose always is produced when cotton or wood-pulp is subjected to overbleaching. The extent of formation of the oxycellulose can be ascertained by determining the copper number or capacity of the bleached cellulose to reduce Fehling's solution, and a limitation of the copper number is not infrequently inserted at the present time in specifications for bleached linters for nitrating purposes. The production of oxycellulose is not carried out for any commercial purpose, as the formation of oxycellulose, like hydrocellulose, is always coincidental with loss in strength of the cotton or other cellulosic fibre.

### ESTERIFICATION.

Before I touch on the esters of cellulose, such as cellulose xanthate, cellulose nitrate, cellulose acetate, etc., reference will be made briefly to a new product which has been developed in the past few years, which is not an ester, but an ether of cellulose. Cellulose ethers are the invention of Professor Lillienfeld, and they are supposed to be, and presumably are, true ethers and not esters. The usual ester produced is the ethyl ester, and, according to the patent, it is formed by the action of di-ethyl sulphate on cellulose which has been subjected to a rather severe hydrolysis or hydration treatment. It is claimed for the ethers that, like simple ethers and not esters, they are not susceptible to saponification, and, as there is no acid radical in their make-up, they remain perfectly neutral and stable. I have not had an opportunity to investigate these ethers nor the claims of the patent, and in so far as I know, at the present time, the product is not being made to any extent in the United States. Here is a small sample of film made from cellulose ether, and this is all I have ever seen. This particular sample is a very excellent product. A review of the patents leads one to believe that the technical

difficulties controlling this reaction must be very considerable, and as we look back on the development of cellulose esters we well realize that the trials and tribulations incident to placing on a commercial basis any new cellulose reaction product are almost enough to discourage new workers in the field.

Of the esters of cellulose, perhaps cellulose nitrate is the one with which everybody is familiar. As a mere reaction, the formation of cellulose nitrate is exceedingly simple, for it consists of merely immersing cotton in a mixture of strong nitric and sulphuric acids. When this process is carried out, depending on the composition of the acids, the time, the temperature, and the character of the material treated, cellulose nitrates of different compositions and workable characteristics are obtained.

Cellulose apparently contains three reactive hydroxyl groups, consequently the limit of esterification is the cellulose tri-ester; for example, cellulose tri-nitrate. As a matter of fact, pure cellulose tri-nitrate is never obtained in practice. The degree of nitration is usually appraised on the basis of the nitrogen content of the ester. Cellulose nitrates are of tremendous industrial importance, more so than ever at present, because cellulose nitrate is the basis of smokeless powder and gun-cotton. But it is also of great importance in the production of materials quite foreign to war purposes, such as the manufacture of celluloid, moving-picture films, artificial silk, artificial leather, and the like. Cellulose nitrate enters into the composition of all these mentioned materials, but for the different purposes cellulose nitrates of different nitrogen content are used; for example, the nitrate used in moving-picture films and celluloid has a nitrogen percentage of, we will say, roughly, 10½ to 11¼ per cent., whereas for varnish purposes it runs from 11½ to 11¾ or even 12 per cent., for powder purposes between 12 and 12½ per cent. approximately, and for gun-cotton purposes between 13 and 14 per cent. All of these nitrates are very rapidly combustible on account of the presence of the unstable oxidizing nitrate radicle, and, other things being equal, the degree of inflammability increases with the nitrogen content. Celluloid, smokeless powder, and gun-cotton all belong to the same family, and it is naturally rather a dangerous family to become too intimately acquainted with, unless you fully understand its disposition and temper.

With celluloid you are all familiar. It is a compound of

camphor and cellulose nitrate of low nitration. These are combined into a dough by the use of a small proportion of common solvent, which after proper working and baking under pressure produces a cake of celluloid. The function of the camphor is to impart softness, but more particularly moulding quality, to the mixture. It seems as if every chemical in Beilstein has been patented or suggested as a commercial substitute for camphor in celluloid manufacture, but, after all has been said and done, camphor still remains the material *par excellence*, and the only one which is universally used. It is quite characteristic of cellulose compounds that some one material performs a certain function in their manipulation, and the result achieved thereby is very difficult to duplicate with any other material or combination. For example, in the manufacture of lacquers, leather, and cloth finishes from cellulose nitrates, amyl acetate has for many years been the prime solvent, and it has been difficult to assail its position. More progress is being made in replacing amyl acetate, however, than in the substitution of camphor in celluloid, for the price of amyl acetate, due to the war, has absolutely compelled the use of other solvents, and various other liquids, such as di-acetone alcohol, acetone oil, various purified ketone mixtures obtained from this, ethyl acetate and ethyl acetate-benzol mixtures, are now being extensively used. Along this same line of preferential use is the use of castor oil with cellulose nitrate in the manufacture of artificial leather, waterproof sheeting, etc. Nothing seems to take the place of it, although almost every other oil, natural and blown, has been tried. Cellulose nitrate seems to have the capacity of carrying a large quantity of castor oil without permitting it to spew out appreciably at moderately high temperatures or over a lapse of time, and castor oil also seems to have the capacity of keeping the coating flexible at low temperatures. Other oils, like oxidized linseed, blown rape, etc., are used for certain purposes, but they are all far less universally applied.

### VISCOSE.

Nearly twenty-five years ago a new cellulose reaction was discovered by Cross in London, and for quite a number of years it created quite a furore, and great and universal application was claimed for it. I refer to viscose, or cellulose xanthate. Working along the lines of the formation of xanthates of simple

alcohols, the adaptation of this reaction to cellulose was worked out. In the production of viscose, cellulose is first treated with a strong caustic soda solution, and there is formed what is termed "alkali cellulose," and this in a moist condition is treated with carbon disulphide, forming sodium cellulose xanthate, deep yellow in color, and pasty or not, depending upon the conditions of the reaction. This product is soluble in the excess caustic soda, forming a deep yellow-colored solution, which at moderately high temperatures quickly coagulates or reverts with the gradual formation of hydrated cellulose, or, even standing at normal temperatures for a considerable period, the same reversion will take place. The solution is also readily coagulated by acids and numerous salts.

Whereas back in 1900 the widest possibilities were claimed for viscose, as a matter of fact only two or three important applications have survived, but they are truly important, and in themselves are ample justification for the early enthusiasm. Undoubtedly you are all familiar with artificial silk, wood silk, or fibre silk, as it is variously called. You ought to be especially familiar with it here in Philadelphia, because, so far as the United States is concerned, it is practically a local industry, and many thousand pounds a week of viscose silk are turned out at the plant of the American Viscose Company at Marcus Hook. Besides silk, a large quantity of thin viscose film, 0.001 inch thick, is produced in France, and is sold in this country under various trade names, such as cellophane, which is used as a transparent protection over candy boxes, in wrapping candies, etc. Thicker films than this are not on the market at present, although I understand that considerable experimental work is being done to adapt viscose film to the photographic industry. I have here a sample of cellophane, also a sample of viscose silk, to which I will refer again later. You may also be interested in some of these various other viscose samples which represent, unfortunately, at the present time, only blasted hopes. (Samples of viscose sheets, viscoid, and viscose cloth prints were shown.)

### CELLULOSE ACETATE.

We now come to a subject to which I have given considerable of my personal time for the past fifteen years, and therefore I hope I may be pardoned if I elaborate on it more extensively

than has been done with the other reactions. Reference is being made to cellulose organic esters, which, so far as commercial products are concerned, mean cellulose acetate. Commercial cellulose acetate is tri-acetate and not tetracetate, and is made by reacting on cotton or rag paper with acetic anhydride and a suitable catalyst or condensing agent. Unfortunately, glacial acetic acid cannot substitute for the anhydride, although a recent foreign patent claims its use for this purpose. Our laboratory has not had time as yet to investigate this claim, but, judging from numerous experiments which have been made in our laboratory with this end in view, it seems exceedingly doubtful that cellulose acetate can be made without acetic anhydride.

Cellulose acetate is on the market in various forms, of somewhat different characteristics. It may look like cotton, as, for example, this sample of fibrous cellulose acetate which I have here, or it may be in a granular or powdered form, like this other sample. Purposely this large sample has been spread out on this table to emphasize its perfect harmlessness. Any one would hesitate to do the same thing with dry cellulose nitrate. In the production of the granular form, acetic anhydride acts on cellulose in the presence of usually a little sulphuric acid, and the reaction mixture is diluted with glacial acetic acid, and as fast as the cellulose acetate is formed it goes into solution, from which it is recovered by precipitation with water. In the production of the fibrous cellulose acetate the above reaction mixture is supplemented by the addition of a non-solvent of cellulose acetate, such as benzol or carbon tetrachloride. The esterification proceeds without solution of the cellulose acetate, which remains in essentially the original form of the cotton used, although very much more bulky and not so strong. By this process it is, of course, not difficult to acetylate cotton cloth, yarns, etc. Here is a sample of cellulose acetate cloth, and also a sample of the cheesecloth from which it was prepared. Both the fibrous process and the granular process are susceptible to certain modifications, so that products of different solubilities and different physical properties can be obtained. It also is possible to further change the solubilities of the products by subsequent treatment after the ester has been formed, and these treatments have been called hydrating the ester, although I am not prepared to say that this is

a true designation of the transformation. The effect of such after-treatments is to increase the solubility of the cellulose acetate in various solvents, particularly in acetone, methyl acetate, alcohol-benzol mixtures, etc.

Up to the present time we have not succeeded in making a fibrous cellulose acetate of as great a range of solubility as it has been possible to obtain with the granular acetate, and it seems as if the wide range of solubility of the granular acetate necessitates a breakdown of the fibrous structure, with possibly some different arrangement within the molecule.

At this point it is perhaps well to refer to the question of viscosity in connection with cellulose products and solutions. Independent of the form or the solubility that the cellulose ester may take, it is possible to make products otherwise identical, but which dissolve in solvents forming for the same concentrations, solutions of entirely different viscosities. The explanation of this undoubtedly lies in the complex nature of the cellulose molecular aggregate: the higher the aggregation, the more viscous the solution, and *vice versa*, and the higher the aggregate the tougher is the film or filament which can be produced from the solution. This can be accepted as generally true.

A given product will not by any means produce solutions of the same viscosity with different solvents, for, with identical concentration, solutions of the same product in different solvents may cover a wide range of viscosity. In mixed solvents sometimes a very little of one component will have a very pronounced effect on the viscosity. For example, the viscosity of a solution of cellulose acetate in tetrachlorethane is tremendously reduced by the addition of either methyl or ethyl alcohol, and, similarly, a very viscous solution of cellulose nitrate, say, for example, in a mixture of amyl acetate and benzol, is very much reduced in viscosity by the addition of one or two per cent. of acetone. In the case of cellulose acetate, methyl or ethyl alcohol is a non-solvent of cellulose acetate, but in the case of the nitrate solution acetone is a very powerful solvent. These solubility peculiarities make a very interesting subject for research, and very little has been done along these lines to date.

The uses to which cellulose acetate is put are very numerous. In general they are essentially the same as those to which cellulose nitrate is adapted, with the single exception of the manufacture of

explosives. In the non-inflammability and slow combustibility of cellulose acetate products really lies their excuse for commercial application, because they are invariably more expensive than nitrate products. Nowadays "Safety First" is the universal cry, and consequently, notwithstanding its cost, cellulose acetate is finding extensive application.

### COMPARISON OF DIFFERENT TYPES OF CELLULOSE PRODUCTS.

Practically very little has been said or written about the comparative qualities and properties of different materials made out of different cellulose compounds, particularly viscose, cellulose nitrate, and cellulose acetate. Among the most important applications are the manufacture of lacquers and varnishes, coated fabrics, photographic and other films, artificial silk, etc., which will be discussed from the point of view of comparative use of the different cellulose compounds.

It is not uncommon for users of one cellulose compound to think that they can take another similar cellulose compound, dissolve it in the same solvents, compound it in the same way, and adapt it to the same uses as they have been accustomed to do with the compound with which they are most familiar. As a matter of fact, almost every cellulose compound has its different solvent requirements, different methods of compounding, and must be handled in its own special way to produce optimum results, and general substitution is not always possible. If people would recognize this and be a little more generous with information, their inquiries could be handled more intelligently and with much better prospect of working out their particular problem.

*Lacquers.*

For a great many years cellulose nitrate lacquers have held undisputed sway. Cellulose acetate lacquers have made relatively small inroads into this field, particularly on account of the high cost and the nature of the solvents which it has been necessary to use. However, a good many thousand gallons a year are used by a few concerns for lacquering certain brass parts of gas and electric fixtures which are subjected to a moderately high temperature. It has been found that a properly-compounded cellulose acetate lacquer gives a finish which stands up a great

deal better for this particular use than does a nitrate lacquer and the very small difference in cost of the finished article is justified by the more durable protection.

Perhaps the oldest use of cellulose acetate in the United States is for insulating very fine copper wire. About seventeen years ago the General Electric Company standardized cellulose acetate insulations on their 0.003-inch wire used on their meter armatures. Previous to this standardization silk had been used as the insulating material, but it was very expensive and bulky, and the reduced space factor provided by the very fine cellulose acetate insulation was an important consideration. For making small meter armatures where there are a great many ends the cellulose acetate coating presented also another advantageous feature. The ends have to be soldered together, and to do this the insulation must be stripped, and the stripping of the cellulose acetate coating was very readily done. About two years ago this stripping was successfully accomplished on linseed oil enamelled wire, and the relatively low cost of the latter caused it finally to displace cellulose acetate for this particular purpose.

*Varnishes.*

At the present time the largest use of cellulose acetate in the United States is for the manufacture of varnishes, particularly airplane cloth varnishes. The business has naturally had tremendous stimulus since the war broke out, and perhaps only those people who are in close contact with it really realize how rapidly airplane manufacture is extending.

Airplane wings consist of a framework covered with unbleached linen, which must be made water-and-air-impervious and drumhead-tight. To accomplish this result, the linen is stretched tightly over the frame and is then varnished with cellulose varnish, which while drying causes powerful shrinkage in the fabric. This shrinkage at times has been known to be so great as to warp and break the frames, but this happens usually when the cloth is stretched too tightly before varnishing. Abroad only cellulose acetate is used as a shrinking varnish, but in this country both cellulose acetate and cellulose nitrate are used, sometimes alone, and sometimes cellulose nitrate is used as the impregnating coating, and then cellulose acetate varnish is used for the finish

coating, the purpose of the latter being to make the wing spark- and flash-proof. Cellulose nitrate varnishes are not so expensive as cellulose acetate varnishes, and consequently some manufacturers let their judgment get the better of them, and standardize on the use of a cellulose nitrate varnish, notwithstanding that it introduces a latent risk, which at present they quite ignore. Undoubtedly they will think better of this when airplanes become more popular as a means of conveyance. Unquestionably the people will demand the elimination of every risk, although, judging by the automobile, who really can predict what the future airplane will look like, or how it will be constructed, and shrinking varnishes may not be used?

It has been suggested that some mention be made of what has been accomplished in the production of transparent wing coverings. Not so very many months ago there was a great deal of newspaper publicity about some airplanes which were made in Germany the wings of which were stated to be covered with a transparent, non-inflammable film which reduced the visibility. Very little has been heard about this lately, and all the meagre information I have ever obtained on this subject was secured from the newspaper and periodical reports and discussion with newspaper editors. Aside from what was disclosed in these publications, I have been able to obtain no information of the precise structure of this wing, except that it was composed of a cellulose acetate transparent film properly strengthened and supported.

In a lecture given in Boston in November by General Squier, which lecture was afterwards published in the JOURNAL OF THE FRANKLIN INSTITUTE of January, 1917, General Squier referred to the desirability of a transparent wing covering for airplanes, and his statement of the requirements of such a transparent covering I will repeat:

1. It must weigh not more than five ounces per square yard.
2. It should present reasonably great resistance to flame.
3. It should be reasonably proof against action of salt water, moist air, extreme dryness, and quick temperature changes.
4. It should not stretch in any direction. Its ability to retain its original form as placed on the airplane is very important.
5. It should have tensile strength of at least 75 pounds per inch width in any direction.

6. Its tendency to tear and split because of tack or bullet holes should be as small as possible.

Now these are mighty hard specifications to hit for any transparent materials known to-day. The ordinary linen used on airplanes weighs three and one-half to four ounces per square yard, and the weight of the coating is approximately two ounces per square yard, and, as there is a top and bottom layer of fabric on each wing, the cloth, plus coating, weighs about 10 to 12 ounces per square yard of wing surface.

A single sheet of cellulose acetate film 0.010 inch thick would weigh per square yard just about the same as the double layer of coated linen cloth. The film has a tensile strength per inch width of about 80 pounds, it is reasonably resistant to flame, is proof against salt water, although it has a very slight absorption of moisture, and when thoroughly seasoned there is very little stretch. Like all other films, however, it does have a tendency to tear and split because of tack holes, and the same would apply, of course, to bullet holes.

In order to overcome this, experiments are being made on a wire-mesh fabric filled with a cellulose acetate film, and a sample of such a fabric I have here. This particular sample is woven of bronze wire, weighs about 25 ounces per square yard, and has a tensile strength of about 100 pounds per inch width. A single layer of this fabric, therefore, weighs about twice as much as the present wing covering per square yard.

In order to lighten this mesh, some experiments have been made with a 12-mesh aluminum wire gauze made out of 0.016-inch wire. With the use of aluminum the finished weight per square yard has been reduced to 17 ounces, but even this is 50 per cent. more than the present wing covering or General Squier's specifications, assuming, when he stated that the transparent wing covering must weigh five ounces per square yard, that this means the single covering. At the present time we are endeavoring to get a more open mesh fabric with even finer wire, so as to give greater transparency and lightness. Assume, however, that the average total wing spread of an airplane is 500 square feet, or 55 square yards, then, even if the wing covering is 10 ounces per square yard heavier than the present covering, this increase would amount to only 35 pounds, which isn't even the difference in weight between a fat and a skinny aviator.

*Artificial Leather and Leather Finishes.*

The only cellulose product used for this purpose in the United States to any extent is a cellulose nitrate and castor oil combination. Cellulose acetate has not found any advantage for this purpose as yet, primarily because it will not blend satisfactorily with castor oil or any other oil. It is also too expensive, and its solvents are too expensive. Most of these artificial leather coatings are loaded with pigments which tend to reduce the inflammability of the cellulose nitrate. There is a distinct prejudice, which amounts almost to prohibition, against the use of a cellulose nitrate artificial leather in car curtains. At present these are coated with materials other than cellulose compounds. The use of artificial leather at the present day—and by this I mean particularly embossed coated cloth—is a very large business, millions of yards being annually produced, and it is really fortunate, with the decreasing leather supply, that such a substitute is available for many purposes. There is still a great deal of room for improvement in artificial leather products, because the present material is not adaptable as a substitute for upper leather on shoes. The coating is not sufficiently resistant to stand the necessary wear.

*Films.*

Viscose, cellulose nitrate, and cellulose acetate are all used in the production of films. As was previously stated, all the viscose on the market is in very thin sheets, approximately 0.001 inch thick, which are used for wrapping purposes, although experimenting is being carried out on thicker products for photographic purposes. Viscose has the disadvantage of not being nearly as waterproof as nitrate or acetate film; that is, it has a relatively high water absorptive capacity, which for some film uses is of no consequence, and for others is a decided detriment. Cellulose acetate has not displaced cellulose nitrate in this country for camera and cinematograph purposes. The reason for this is entirely commercial, and has no bearing on the intrinsic merit of cellulose acetate for this purpose. In France and Germany the use of non-inflammable cinematograph films is compulsory, and ultimately it will be in this country, although when this becomes the case it does not necessarily mean that the film will be cellulose acetate, for it might be viscose or a cellulose ether film. For various uses where the non-inflammable feature is of distinct

advantage cellulose acetate films are gradually being substituted for celluloid films, and are finding adaptation where celluloid has never been used, and this in spite of the very much higher cost of the cellulose acetate film. Many thousands of goggles are produced every week of the non-inflammable film, and I have here a number of samples of various sizes and color combinations. For other forms of protective masks and helmets these films are also used, and the advantage of the non-inflammability, of course, is self-evident. Visible indexes or visible card systems are extending rapidly. A great deal of celluloid is used as a transparent covering in the manufacture of these indexes, and some of the largest concerns are wide awake to the great danger of the use of celluloid in connection with these valuable and difficultly replaceable records, and are demanding the substitution of a non-inflammable film for this purpose. A novel use of cellulose acetate film has been tried this winter near Boston. A street railway company found itself short of closed-car equipment, and was unable to secure new cars. It therefore made over some of its open cars into closed smoking cars by installing heaters and inserting cellulose acetate windows in the curtains.

There are numerous other places where the substitution of a waterproof, non-inflammable film seems to be desirable.

*Cellulosic Filaments.*

Perhaps the most fascinating application of cellulose compounds is in the manufacture of artificial silk, and incidentally coarse filaments as substitutes for horse-hair and artificial bristles. Recovered cellulose filaments are not particularly suitable for bristle purposes, because they distort so badly when wet. Cellulose nitrate is not adaptable on account of its high inflammability. This leaves cellulose acetate, then, as the most suitable compound, but even cellulose acetate bristles have a defect in common with the others; that is, they lack resiliency or life, and when sharply bent do not spring back to their original position. This is well illustrated in this hair-brush, which was made in England and arrived in the condition shown here. This brush is several years old, as well as this little clothes brush in which acetate bristles make up the body of the brush, but the outer edge is made up of natural bristles. This is still in excellent condition.

Unfortunately there is not sufficient time to discuss in great detail the various processes of manufacturing artificial silk and the differences in the products obtained. Briefly, however, there are four processes being operated at the present day—the Chardonnet or cellulose nitrate process, the Cuprammonium process, the Viscose process, and the Cellulose Acetate process. The final products of the first three processes are not chemically very dissimilar, as they are all straight recovered cellulose, or hydrated cellulose. It is true that the Chardonnet or cellulose nitrate process produces directly a filament composed of a cellulose ester, but this, of course, is so highly inflammable that the silk must go through a process of denitration to eliminate the nitrate radicle, leaving the silk ultimately as recovered cellulose. Of these three processes, the viscose process is the more recent and is making the most rapid strides, and bids fair to ultimately replace the other two. All these silks, however, have one very fundamental defect, and that is their great loss of strength when wet. The tensile strength will drop off 75 to 80 per cent. A process called the Sthenosage process was invented some time ago for treating artificial silk with formaldehyde and other chemicals for the purpose of increasing its strength when wet. In so far as I can learn, however, this process has not had extensive application, and I have been informed that the chief reason for this has been that it affects the dyeing properties of the silk, and the process is difficult to control.

The baby in the artificial silk field is cellulose acetate silk. Inasmuch as the acetyl radicle does not impart inflammability to the cellulose, it is not necessary to remove it, and as cellulose acetate is essentially waterproof, the silk is likewise so. Cellulose acetate silk is very much stronger wet than any other type of artificial silk. Whereas viscose silk, for example, will lose 75 to 80 per cent. of its tensile strength when wet, cellulose acetate will lose only 20 to 25 per cent. of this strength, and consequently, whereas the dry silks have about the same strength, the wet acetate silk has over three times the strength of wet viscose silk. Viscose in an atmosphere saturated with moisture at normal temperatures will pick up about 30 per cent. of its original weight of water, with proportionate decrease in strength, whereas acetate silk will pick up only about 6 per cent. of water, and the consequent decrease in strength is very little. The relative loss of

strength of these two types of silk can be illustrated by this very simple experiment. The silk used in this test is 150 denier, and I will make a double loop of it and hang on it a 500-gramme weight, which it ought to readily support when dry. If this viscose silk now is moistened, the loss in strength is so great and rapid that the silk will no longer sustain this weight. If this same experiment be repeated with cellulose acetate silk, as can be readily seen, the strength of the silk, wet as well as dry, is entirely sufficient to carry the weight.

Chardonnet, Viscose, and Cuprammonium silks are all practically straight cellulose, and in their dyeing properties they are identical with cotton, although usually, on account of the treatment they have gone through, their affinity for the dyes is slightly greater. Cellulose acetate silk, however, being a cellulose compound, has quite different dyeing properties from the other artificial silks, and it has different dyeing properties than any other fibre, so that in this respect alone it constitutes a product of entirely new possibilities. Cellulose acetate silk of the type of this sample cannot be dyed with direct cotton colors nor with sulphur, acid, or vat colors unless the alkali used in the dyeing is of sufficient strength and the treatment sufficiently drastic to partially saponify the silk.

Those who are familiar with dyeing methods can readily see that the cross-dyeing possibilities of cellulose acetate silk unions are quite outside the range of those of any other artificial silk fibre. For example, it is possible to weave a fabric of cotton warp and acetate silk filling or pattern and dye the fabric with a direct cotton color, leaving the silk uncolored, or it is possible to dye the fabric with a basic color without mordant, thereby coloring the silk and leaving the cotton uncolored. The same can be done with an artificial silk union, part acetate silk and part viscose silk, and even in cotton, wool and cellulose acetate silk unions it is possible to color the cotton and the wool and leave the silk uncolored. Cellulose acetate silk is also a very good resist to logwood dyes, which is another distinct advantage. (You may be interested later in looking at these few samples of artificial silk which I have here—some acetate silk, and others viscose silk.)

# PHYSICS OF THE AIR.*

BY

W. J. HUMPHREYS.

### INEQUALITY OF SEASONAL TEMPERATURE CHANGE OF LOWER AND UPPER ATMOSPHERE.

As just explained, if $T_2$ is the absolute temperature of the black surface that gives off radiation equivalent to that sent out by the convective portion of the atmosphere and $T_1$ the absolute temperature of the isothermal region, then

$$T_1 = T_2/\sqrt[4]{2} = 0.84\ T_2, \text{ roughly.}$$

Hence the greater $T_2$, or the warmer the lower atmosphere, if its composition remains the same, the greater the difference between $T_1$ and $T_2$, or the greater the contrast between the temperature of the lower atmosphere and that of the isothermal region. This is in keeping with the observed fact (Fig. 15), that the seasonal difference in the temperature of the isothermal region, while in the same sense as that of the lower atmosphere, is not so great as is the latter. Because of seasonal differences in the composition of the lower atmosphere, especially in the average amount and distribution of water vapor, there can be no constant relation between the above temperature differences—only the qualitative relation as given.

### HEIGHT OF THE ISOTHERMAL REGION.

If $H_1$ is the height and $T_1$ the temperature of the under surface of the isothermal region above the level $H_0$, whatever that may be, whose temperature is $T_0$, then

$$H_1 = H_0 + \int_{T_0}^{T_1} \frac{dH}{dT} dT$$

As above explained, the greater the temperature of the lower atmosphere, the greater the difference between this temperature and that of the isothermal region, or, in symbols, the greater $T_0$ the greater $T_0 - T_1$, and therefore the greater $H_1$. Hence the isothermal region should be at a greater elevation during summer

* Continued from page 178, vol. 184, August, 1917.

than during winter. Another way of showing this same thing is as follows:

Let the difference between the summer and winter temperatures of the lower atmosphere be $\Delta T_2$ throughout, and the corresponding difference between the temperatures of the upper atmosphere $\Delta T_1$, then, according to the above theory, $\Delta T_1 = 0.84\Delta T_2$, roughly. This, as already explained, is a radiation result. The inequality or $0.16\Delta T_2$ is produced by convection. Now if $h$ is the change in elevation corresponding to 1° C., we have

$$\Delta H = 0.16\Delta T_2 h.$$

But, $\Delta T_2$, winter to summer, is roughly 12° C., and $h$ about 110 metres. Hence the change in the seasonal elevation of the isothermal region, if there is constancy in atmospheric composition, is, roughly,

$$\Delta H = 0.16 \times 12 \times 110 = 211.2 \text{ metres.}$$

It must be distinctly noted, however, that many disturbing elements, such as quantity and distribution of water vapor, frequency and extent of cirrus clouds, and the like, so modify these simple relations that they apply only to average conditions, and to them but approximately.

### STORM EFFECTS ON TEMPERATURE GRADIENTS.

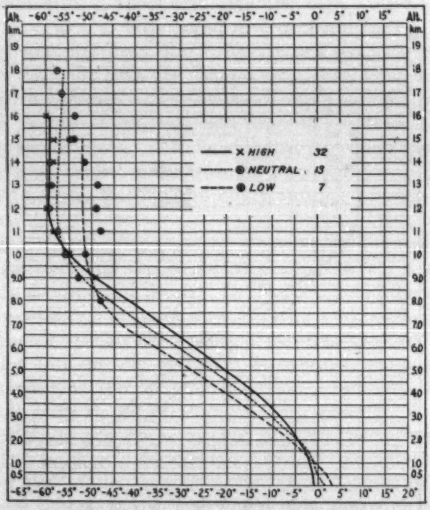
The average of a season's (winter or summer) vertical temperature gradients gives a fairly regular curve, and, of course, the same would be true of the average of these averages, or what might be called the annual gradient for any given locality. However, each particular flight yields its own temperature-altitude curve, which differs more or less from others of the same place and season, especially in the values of the gradients in the first two or three kilometres elevation, in the absolute temperatures at other levels, and in the location of the upper inversion.

With the view of determining the causes of some of these flight-to-flight irregularities, both the summer and the winter records from which the corresponding seasonal gradients were determined were grouped, according to the heights of the barometer at the times and places of observation, into "highs," "neutrals," and "lows." Thus the "highs" belong to barometric readings of 765 mm. or more; the "neutrals" to readings from 757.5 mm. to 762.5 mm.; the "lows" to readings of 755 mm.

or less, all reduced to sea level. While the observations, especially those classed as lows, are not sufficiently numerous to give averages entirely free from irregularities, nevertheless they produce distinct types of curves that any larger number probably would but slightly modify.

Fig. 16 shows the winter averages, respectively, of 32 highs, 13 neutrals, and 7 lows. Commonly, as the figure shows, a high

FIG. 16.




Temperature gradients at different pressures, winter.

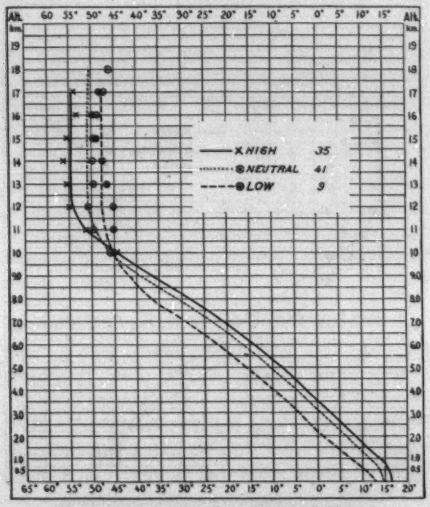
barometer in the winter is accompanied by low surface temperatures, a slow decrease of temperature up to an elevation of about three kilometres, relatively warm air, in general, between the levels of two and nine kilometres, a high upper inversion, and a cold isothermal region. A winter low, on the contrary, and in comparison with a high of the same season, is accompanied by warm surface temperatures, a more rapid decrease of temperature with increase of elevation through the first three kilometres,

relatively cold air from, roughly, two to nine kilometres elevation, a low upper inversion, and a warm isothermal region.

The normal barometer, as one would expect, is accompanied by intermediate values in all particulars.

The corresponding summer gradients (averages, respectively, of 35 highs, 41 neutrals, and 9 lows), given in Fig. 17, show, except near the surface, where the lows remain cold and the highs warm, the same characteristics as do those of winter.

FIG. 17.




Temperature gradients at different pressures, summer.

Both the summer and the winter curves follow exactly the averages of the observations, except for slight deviations in the isothermal region, as shown. Naturally, the higher the level the fewer the observations secured, a fact that explains the irregularities in the isothermal region and justifies, in a sense, smoothing the curves in an effort to distinguish clearly the different types of gradients.

An obvious contributing cause of these differences in temperature is the warming of the air by compression and its

cooling by expansion incident to barometric changes; an amount which, starting with dry air at 0° C., is given, as explained on page 163, by the equation

$$\frac{dT}{dp} = \frac{77.6}{p},$$

in which $p$ is the pressure, expressed in millimetres of mercury, and $dT$ the change of temperature in degrees Centigrade.

According to Figs. 16 and 17, the temperature at the altitude of four kilometres is about 7° C. warmer both winter and summer in the regions of high barometric pressure than it is in the regions of low pressure. But to secure this temperature difference as a result of pressure change only, would require a rise or fall of the barometer at this level of about 40 mm., or something like 70 mm. at sea level, and, since this is several-fold the average pressure change, it is obvious that the observed temperature differences cannot in the main be accounted for in this way, though, of course, the pressure effect must be present to some extent.

Another contributing cause of temperature differences, generally associated with the height of the barometer, is the clear and cloudy condition of the sky, or the humid and the dry state of the atmosphere. A barometric high, as we know, commonly is accompanied by clear skies and a dry atmosphere, while in the region of a low the sky ordinarily is overcast, the atmosphere relatively moist, and precipitation abundant—conditions that have much to do with air temperatures. Thus, generally, at the end of any consecutive 24 hours of clear weather the surface of the earth will be warmer in the summer time and colder in the winter because of the unequal lengths during those seasons of the day and night. On the whole, the earth gains heat, especially in clear weather, during summer and loses it in the winter. A cloud covering, however, greatly reduces the rate of this gain or loss, and therefore during winter the surface temperature is lowest when the barometer is high and the earth can radiate most freely to space, while it is warmest when the barometer is low and the sky so overcast as to check radiation loss.

In the summer time, as explained, the conditions of gain and loss of heat are the reverse of those during winter, consequently the highest summer surface temperatures accompany the high barometer, or clear weather, while the lowest accompany cloudy skies.

When the barometer is distinctly above normal the temperature fall with increase of altitude up near the stratosphere generally follows approximately the adiabatic curve for dry air. When, however, the barometer is low the temperature gradient usually is far less constant at all elevations, owing to irregularities in the humidity distribution and the consequent varying amounts and places of precipitation. In many cases the temperature gradient over varying heights is essentially the adiabatic curve for saturated air at the prevailing temperature and pressure; that is, a fall of temperature per given change in altitude is less, other things being equal, the greater the amount of uncondensed humidity present.

Since the curves of Figs. 16 and 17 are the averages of a number of flights, it may be approximately correct, in an effort to account for their differences, to start with something like average conditions and trace the consequences. Let these conditions be a moist atmosphere in the one case and a dry one in the other, each having the same temperature as the other at all levels. The moist atmosphere, because a better radiator than the dry, will, under the same conditions of exposure and at the end of the same interval of time, cool to a lower temperature, but in so doing—that is, in getting rid of its own heat most rapidly—it at the same time supplies heat at greater rate to any neighboring region that receives it by radiation only. Therefore when the lower atmosphere is moist it will, under like conditions, radiate heat most rapidly to and through the always dry air of the isothermal region, and while getting cold itself will at the same time warm this region to a temperature above its average. On the contrary, in the region of a high barometer the lower air, being relatively dry and therefore a poor radiator, will conserve its own temperature, but in so doing will allow the isothermal region to get cold in comparison with its temperature during the prevalence of a low at the same season.

Since the temperature of the isothermal region depends essentially upon the amount of radiation received from the lower atmosphere, it follows that, on the average, the temperatures of the two regions must vary in the same sense, or warm and cool together, and this, indeed, is just what happens, as the winter and summer gradients of Fig. 15 indicate. It is surprising, therefore, when we find the temperatures of these regions varying in the

opposite sense, the one getting warm while the other is getting cold. But it must be remembered that the lower atmosphere is warmed convectionally, in large part, while the upper air is warmed almost wholly by radiation. Further, convection must obtain wherever the actual temperature differs from that which gives the equilibrium between absorption and radiation. Hence whatever increases radiation from the lower air, increase of humidity or temperature, or both, must tend to increase the temperature of the isothermal region, and whatever decreases this radiation, decrease of humidity or temperature, or both, must decrease its temperature below that which it otherwise would have. Now the average seasonal change of the lower atmosphere is primarily one of temperature, while the average storm difference of a given season appears to be largely one of humidity. The high temperature of summer obviously affords a more abundant radiation than the relatively low temperature of winter and should give, as we have seen, a warmer isothermal region. Similarly, the different intensities of radiation from humid and relatively dry air would lead one to expect the stratosphere to be warmer over a cyclonic than over an anticyclonic area.

Another important factor, presumably the controlling one, in the temperature contrasts between cyclonic and anticyclonic regions is the vertical movement of the atmosphere, downward in the former, upward in the latter. Probably, at least, a large portion of the anticyclonic excess of air that gives the increase of pressure and makes good the loss by outflow is fed in at considerable altitudes, though below the isothermal level. If the air movement is as here supposed, there necessarily must be dynamical heating throughout the lower atmosphere, partly because of the initially increased pressure, but mainly through descent. At the same time the atmosphere of the isothermal region would be more or less lifted and cooled by the resulting expansion.

Conversely, if, as there is much reason to believe, the chief removal of atmosphere over cyclonic areas is also from considerable altitudes, but below the isothermal region, the lower atmosphere must be dynamically cooled, partly by virtue of the immediately decreased pressure, but chiefly through ascent. The stratosphere would be lowered and its temperature thereby increased. It seems likely, too, that under these conditions there would be a somewhat continuous slow movement of air from the

stratosphere down into the region of the troposphere (convection region), with, of course, counterflows elsewhere and subsequent readjustments of the level of the isothermal region as temperature and other conditions changed.

Radiation intensity, barometric pressure, and vertical circulation, therefore, appear all to coöperate in lowering the temperature of the troposphere and raising that of the stratosphere in cyclonic regions. Conversely, they appear equally to coöperate in raising the temperature of the troposphere and lowering that of the stratosphere in anticyclonic regions.

The above temperature conditions are averages, respectively, for the whole of cyclonic and anticyclonic areas. Subdivisions of these areas show temperature contrasts between their several quadrants, owing, in part at least, to differences in horizontal wind direction and the distribution of condensation and evaporation. This interesting detail, however, scarcely belongs to a discussion of the isothermal region, but rather to an account of the two types of weather concerned, under which heads it will receive further consideration.

### RELATION OF THE ISOTHERMAL REGION TO LATITUDE.

It is well known that both the height and temperature of the stratosphere are functions of latitude. In the northern hemisphere, during summer, the under surface of the stratosphere gradually rises from about 10 kilometres above sea level at latitude 60° to approximately 15 kilometres at the equator, while the temperature correspondingly changes, roughly, from −45° C. to −70° C. Similar altitude and temperature changes of the stratosphere with latitude obtain, so far as observed, during all seasons and in both hemispheres, though the exact cause, or causes, of these variations is not known.

Changes in the amount of radiation from below and changes in the diathermacy of the upper air at once occur as possible explanations of the above latitude effects. The warm surface temperatures of equatorial regions necessarily cause, through vertical convection, abundant cloudiness at high altitudes. These clouds, in turn, intercept much of the radiation from below, either reflecting or absorbing it. The portion reflected obviously does not directly warm the cloud, but somewhat raises the temperature of the troposphere, while a portion of that which is absorbed

merely produces evaporation rather than a change of temperature. Hence, presumably, the high clouds of equatorial regions, and also the considerable humidity there at great altitudes, owing to the persistent vertical convection, raise the level and thereby decrease the temperature of the effective radiating surface, thus diminishing the intensity of the radiation that reaches the stratosphere, and permitting its temperature to be correspondingly low.

Some of the heat thus absorbed in the lower atmosphere conceivably may manifest itself in an acceleration of interzonal circulation in equatorial regions and an increase of outgoing radiation at higher latitudes.

There is, of course, abundant cloudiness over the higher latitudes as well as in equatorial regions, but there the atmosphere is more generally descending instead of ascending, the clouds low, the humid layer shallow, and consequently the effective radiating surface and the stratosphere comparatively warm.

Conceivably, too, the composition of the stratosphere may differ with latitude. Because of auroral concentration and because of any poleward drift there may be of the upper atmosphere, perhaps there is more ozone, intensely absorptive of earth radiation, over high than over low latitudes. Doubtless, also, there are local differences in the water vapor content of the stratosphere, but at most the absolute humidity of this region must be exceedingly small, as is obvious from its excessively low temperature, and from the fact that marked temperature changes of the upper atmosphere, amounting at times to 20° C., or more, never, so far as known, produce clouds above the high cirrus; that is, above the upper levels of the troposphere.

As previously stated, the essential cause of the relation of the temperature of the stratosphere to latitude is not known, but it seems probable that this relation may depend, in part at least, upon the distribution of clouds, water vapor, and ozone, and therefore that each deserves further observation and study in this connection.

## CHAPTER V.

### COMPOSITION OF THE ATMOSPHERE.

IN the previous discussions the actual composition of the atmosphere was of little or no importance. In some that follow, however, barometric hypsometry, for instance, or the determina-

tion of altitude from pressure, it is a factor that cannot always be neglected. It will be convenient, therefore, before considering such subjects, to note of what substances the atmosphere consists and in what proportions they occur.

If we disregard such obviously foreign things as dust, fog, and cloud, then whatever remains appears to be ideally homogeneous, under ordinary conditions, and in many discussions, such as most of those of the previous pages, it conveniently may be so treated. The Greek philosophers, indeed, regarded the atmosphere as one of the four elements that singly and combined constituted the whole of the material universe. To them it was an element in the strictest sense which could not be divided into dissimilar parts.

In reality it is not even a single substance like water, much less a single element, but a mixture of a number of gases and vapors that radically differ from each other in every particular; nor are even the relative percentages of the several distinct constituents at all constant. The story of the chemical conquest of the atmosphere, from the calcination and combustion experiments of the seventeenth and eighteenth centuries that established its complexity down to the refined analyses of the present day that note and account for even the faintest traces, is full of instruction and inspiration. However, it is practicable to give here only some of the final results.

According to Hann,[16] the chief independent gases that are blended into a dry atmosphere at the surface of the earth, and their respective volume percentages, are as follows:

| Element..... | Nitrogen | Oxygen | Argon | Carbon dioxide | Hydrogen | Neon | Helium |
|---|---|---|---|---|---|---|---|
| Volume, per cent.. | 78.03 | 20.99 | 0.94 | 0.03 | 0.01 | 0.0012 | 0.0004 |

In addition to these, krypton and xenon also occur as permanent constituents of the atmosphere. There are also many substances, such as radio-active emanations, the oxides of nitrogen, ozone, and, above all, water vapor, that are found in varying amounts, but of these only water vapor commonly forms an appreciable percentage of the total atmosphere, a percentage that depends chiefly upon temperature in the sense that, for any given pressure, the higher the temperature the greater the possible percentage of water vapor. This relation holds up to the boiling-

[16] "Lehrbuch der Meteorologie," 3d ed., p. 5.

point of water at the given pressure, when, assuming saturation, there will be nothing but water vapor present, or its percentage will become 100.

Because of this relation of water vapor to temperature its volume percentage decreases from the equator towards the poles, while that of each of the other constituents of the atmosphere correspondingly increases. The annual average values, again quoting from Hann,[17] are;

| | Nitrogen | Oxygen | Argon | Water vapor | Carbon dioxide |
|---|---|---|---|---|---|
| Equator .... | 75.99 | 20.44 | 0.92 | 2.63 | 0.02 |
| 50° N. ..... | 77.32 | 20.80 | 0.94 | 0.92 | 0.02 |
| 70° N. ..... | 77.87 | 20.94 | 0.94 | 0.22 | 0.03 |

Except for the change in the amount of water vapor, the composition of the surface atmosphere is substantially the same at all parts of the earth. Its composition at different elevations, however, probably differs greatly, as considerations presently to follow will indicate.

But this discussion requires the use of barometric hypsometry. Therefore an equation must be developed for this purpose.

### BAROMETRIC HYPSOMETRY.

Let $\rho$ be the density of the atmosphere at the height $h$, and $p$ its pressure in dynes per square centimetre. Then at the level $h$ the decrease in pressure, $-dp$, due to the increase in height, $dh$, is given by the equation,

$$-dp = \rho g\, dh \qquad (1)$$

in which $g$ is the acceleration of gravity at the point in question.

To within limits practically negligible the density of the atmosphere is directly proportional to the pressure—*Boyle's law;* inversely proportional to the absolute temperature—*Charles's law;* and directly proportional to the sum obtained by adding together the molecular weights of the several gases present, each multiplied by the ratio of its partial pressure (the pressure which it alone produces) to the total pressure—*Avogadro's law.*

If, now, $\rho_0$ is the density of dry air at the temperature 0° C., and under the pressure $p$, then

[17] *Ibid.*, p. 5.

$$\rho = \rho_0 \frac{\left(1 - 0.378\frac{w}{p}\right)}{1 + at} \quad \ldots\ldots (2)$$

in which $w$ is the partial pressure of the water vapor present, $t$ the existing temperature in degrees Centigrade, and $a$ the coefficient of gas expansion, or $\frac{1}{273}$, at 0° C.

Substituting the value of $\rho$, as given by equation (2), in equation (1), we have

$$-dp = \rho_0 g \frac{\left(1 - 0.378\frac{w}{p}\right)}{1 + at} dh \quad \ldots\ldots (3)$$

Further, let $H$ be the height of the "homogeneous" atmosphere, or height it would have if everywhere at the same temperature and pressure, and therefore of constant density. Obviously, according to Boyle's law, the value of $H$ is independent of the actual value of the pressure. If, for instance, the amount of gas is doubled, $p$ becomes doubled and the density doubled, and consequently $H$ remains unchanged. Similarly for any other multiple or submultiple of the pressure.

At any given place the pressure, $p$, clearly is equal to the continuous product of the gas density, local acceleration of gravity, and homogeneous height; that is,

$$p = \rho_0 g H \quad \ldots\ldots (4)$$

Hence, substituting in (3)

$$-dp = \frac{p}{H} \frac{\left(1 - 0.378\frac{w}{p}\right)}{1 + at} dh \quad \ldots\ldots (5)$$

But, as is seen from equation (4), $H$ is inversely proportional to $g$. Hence before we can assign a numerical value to $H$ it is necessary to specify the value of $g$ to which it applies. Now the height of the "homogeneous" atmosphere corresponding to temperature $t$ and gravity $g$ is found by multiplying any barometric height $b$, representing, under gravity $g$, a pressure $p$, by the ratio of the density of mercury at the temperature for which $b$ was determined to the density of dry air at the given temperature $t$, and assumed pressure $p$. For 0° C. and normal gravity $G$ (that is, the value of gravity acceleration at sea level at latitude 45° N.),

$$H_G = 7991 \text{ metres.}$$

Therefore $H$, or, specifically,

$$H_c = 7991 \frac{G}{g} \text{ metres.}$$

Hence, substituting in (5), and measuring in metres,

$$-7991 \frac{dp}{p} = \frac{\left(1 - 0.378 \frac{w}{p}\right)}{1 + at} \frac{g}{G} dh \quad \ldots\ldots (6)$$

Integrating this from $h_0$, $p_0$ to $h$, $p$, we have

$$7991 \log_e \left(\frac{p_0}{p}\right) = \int_{h=o}^{h=h} \frac{\left(1 - 0.378 \frac{w}{p}\right)}{1 + at} \frac{g}{G} dh \quad \ldots\ldots (7)$$

However, the integration is not rigidly possible, since $t$ and the ratio $\frac{w}{p}$ both are more or less irregular and variable functions of $h$. The value of $g$ is also a function, but, for any given place, a fixed one, of $h$. Nevertheless, when the coincident values of $p$, $t$, and $w$ are closely known, as they may be, it is quite possible closely to determine the corresponding values of $h$; that is, to obtain an approximate solution of the above nonintegrable equation. This, of course, is most accurately done by dividing the total height into intervals over each of which $t$ and the ratio $\frac{w}{p}$ both change very nearly uniformly.

If at the elevation $h_0$ we have the ratio $\frac{w_0}{p_0}$ and at $h$ the ratio $\frac{w}{p}$, then, when $h - h_0$ is not too great, we may, with but little error, assume the ratio constant and its value for the interval in question to be

$$\left(\frac{w_0}{p_0} + \frac{w}{p}\right)/2 = W \quad \ldots\ldots (8)$$

Also, if the temperature varies approximately uniformly between the given levels, we can assume, again with but little error, the mean, $t_m$, of the two limiting temperatures to be that of the whole layer between $h$ and $h_0$. Finally, as the value of $g$ changes but little through all attainable levels in the atmosphere, its mean value, $g_m$, between the two levels, may be used as a very close approximation.

Hence, with all these approximations,

$$H = 7991 \log_e \left(\frac{p_0}{p}\right) \frac{1 + at_m}{1 - 0.378W} \frac{G}{g_m} \quad \ldots\ldots (9)$$

If, instead of natural logarithms with base $e$, ordinary logarithms with base 10 are used, the equation becomes

$$H = 18400 \log_{10}\left(\frac{p_0}{p}\right)\frac{1+al_m}{1-0.378W}\,\frac{G}{g_m} \qquad (10)$$

Now $g_m$ differs in general from $G$ both because of difference in latitude and because of difference in elevation. Thus the shape of the earth causes the value of gravity so to vary at sea level that at latitude $l$

$$g_l = G(1-0.0026\cos 2l);$$

while with elevation it varies inversely as the square of the distance from the centre of the earth.

Let $R$ be the radius of the earth at the place of observation, and $d$ the elevation at which the value of $g$ is desired. Then

$$\frac{g_0}{g_h} = \frac{(R+d)^2}{R^2}$$

and

$$g_h = g_0\left(1-2\frac{d}{R}+3\left(\frac{d}{R}\right)^2-4\left(\frac{d}{R}\right)^3+\ldots.\right) \qquad (11)$$

But even if $d$ is as great as 10 kilometres, the fraction $\frac{d}{R}$ is still so small, roughly $\frac{1}{637}$, that an error of less than 1 in 400,000 will be made by writing

$$g_h = g_0\left(1-2\frac{d}{R}\right)$$

Hence, finally,

$$g_l{}^d = G\,(1-0.0026\cos 2l)\left(1-2\frac{d}{R}\right)$$

and

$$h = 18400 \log_{10}\left(\frac{p_0}{p}\right)\frac{1+al_m}{1-0.378W}\,\frac{1}{(1-0.0026\cos 2l)}\,\left(\frac{1}{1-2\frac{d}{R}}\right) \qquad (12)$$

But as the amount of water vapor in the atmosphere seldom amounts to more than 2.5 per cent. of the total gases present, it follows that

$\frac{1}{1-0.378W} = 1 + 0.378\ W$, to within 1 part in 10,000. Similarly,

$\frac{1}{1-0.0026\cos 2l} = 1 + 0.0026\cos 2l$, usually to within 1 part in 1,000,000, and

$\left(\frac{1}{1-2\frac{d}{R}}\right) = 1+2\frac{d}{R}$, when $d$ = 10 kilometres, to within 1 part in 100,000.

Hence, for convenience, if $d = \frac{h_0+h}{2}$, we may write as a close approximation,

$$h = 18400 \log_{10}\left(\frac{p_0}{p}\right)(1+at_m)(1+0.378W)(1+0.0026\cos 2l)\left(1+\frac{h_0+h}{R}\right) \ldots (13)$$

Since the two pressures, $p_0$ and $p$, occur in this equation as a ratio, it is correct and customary to substitute for them the corresponding barometric readings—properly corrected, of course—for $t$ and $g$. But as the value of $g$, in turn, depends upon $h$, the evaluation of the latter would appear to require a series of approximations. Rigidly this is true, but, as the value of $g$ varies so little through attainable altitudes, a very rough approximation to the value of $h$ is sufficient for the altitude correction of $g$.

Obviously, in general, the recorded values of $t$, $W$, and the barometric reading $b$ are all in error, and therefore it will be well to see what effects such errors will have on the computed value of $h$.

Assuming an error to be made in $b$ only, amounting to $db$, we have from (13), substituting $\frac{b_0}{b}$ for $\frac{p_0}{p}$ and using natural logarithms, $dh = -7991 \frac{db}{b}(1+at_m)(1+0.378W)(1+0.0026\cos 2l)\left(1+\frac{h_0+h}{R}\right)$ or, very approximately,

$$dh = -7991 \frac{db}{b}(1+at_m)$$

Hence the greater the altitude, or the smaller the value of $b$, the more important become the errors in pressure. Under the reasonable conditions that $t_m = 0°$ C., $db = 1$ mm., and $b = 500$ mm., corresponding to an altitude of, roughly, 3350 metres, the error $dh = 32$ metres, nearly. Hence, to avoid serious errors in barometrically ascertained altitudes, the value of $b$ must be determined with great care.

Assume, now, an error in the temperature amounting to $dt$, then $dh = 18400 \log_{10}\left(\frac{b_0}{b}\right) a\, dt$, approximately.

Hence

$$\frac{dh}{h} = \frac{a\,dt}{1+at_m} = \frac{dt}{t_m+273} = \frac{dt}{T}$$

in which $T$ is the absolute temperature.

Again, let $b = 500$ mm., $t_m = 0°$ C., and $dt = 1°$ C. Then

$$dh = 12.25 \text{ metres, approximately.}$$

Clearly, then, to avoid considerable errors in hypsometric altitude determinations the temperature must also be known with considerable accuracy.

Finally, assume an error in the value of $W$, that is to say, in $\left(\frac{w_0}{p_0}+\frac{w}{p}\right)/2$. As there should be no error of consequence in $w_0$, assuming it to be the vapor tension at the surface of the earth, it follows that the chief error is likely to be in $w$, the vapor tension at the elevation where the total pressure is $p$.

Let $w$ and $p$ both be expressed in terms of barometric height, then

$$dh = 18400 \log_{10}\left(\frac{b_0}{b}\right)(1+at_m)\ 0.378\frac{dw}{2b}$$

If, as above, we let $b = 500$ mm., then $w$ can scarcely be more than 10 mm. Hence, assuming $b_0 = 760$ mm., $t_m = 0°$ C., and a 10 per cent. or 1 mm. error in $w$,

$$dh = 1.35 \text{ metres, approximately.}$$

Hence an error in the value of the humidity produces only a small effect on the altitude determination in comparison with that due to an error of the same order in either the temperature or the total pressure.

Errors in the force of gravity, whether from latitude or from elevation, have already been shown to be very small.

For all ordinary purposes, therefore, altitudes in metres may be determined by the greatly simplified equation,

$$h = 18400 \log_{10}\left(\frac{b_0}{b}\right)(1+at_m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Obviously these hypsometric formulæ apply only to so much of the atmosphere as is of substantially constant composition, since the same "homogeneous" altitude, 7991 metres, is assumed throughout. Clearly, too, this condition of constant composition must apply, very approximately, up to the greatest altitude to which vigorous vertical convection extends, or in middle latitudes, as we shall see later, to an elevation of about 11 kilometres above sea level.

Beyond this level, up at least to the greatest altitude yet reached by sounding balloons and presumably much higher still, the temperature changes comparatively little with change of elevation. Hence in this region there can be relatively little vertical movement of the atmosphere, and therefore a chance, presumably,

for the several gases, oxygen, nitrogen, and others, to distribute themselves, each as though it alone were present.

For this more or less isothermal region, then, it is sufficient for most purposes to use the simple equation,

$$-dp = p\frac{dh}{H} \quad \ldots\ldots\ldots\

mation. It is not convenient, however, for numerical calculations, but for this purpose can be put into the following form:

$$\log_{10} p = \log_{10} p_0 - \frac{0.434295}{H}(h - h_0) \quad \ldots\ldots (16)$$

Equation (14) is applicable as far up as the composition of the atmosphere is essentially constant, or to an elevation of about 11 kilometres, while above that level, where, owing to the practical absence of vertical convections, each gas presumably is distributed substantially as though it alone were present, equation (16) may be used, with, of course, the proper value of $H$ for each gas considered.

This value is given by the following equation:

$$H = 7991 \frac{D_a}{D} \frac{T}{273}$$

in which $T$ is the absolute temperature, $D_a$ the density of dry air, and $D$ that of the gas in question, both at the same pressure (no matter what) and at 0° C.

Table I, computed by the aid of equations (14) and (16), and Fig. 18, drawn in accordance with this table, give the approximate composition and barometric pressure of the atmosphere at various levels. The assumptions upon which they are based are in close agreement with the average conditions of middle latitudes, and are as follows:

TABLE I.

*Percentage Distribution of Gases in the Atmosphere.*

| Height in kilometres | Gases | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Argon | Nitrogen | Water vapor | Oxygen | Carbon dioxide | Hydrogen | Helium | Total pressure in millimetres |
| 140 | .... | 0.01 | .... | ..... | .... | 99.15 | 0.84 | 0.0040 |
| 130 | .... | 0.04 | .... | ..... | .... | 99.00 | 0.96 | 0.0046 |
| 120 | .... | 0.19 | .... | ..... | .... | 98.74 | 1.07 | 0.0052 |
| 110 | .... | 0.67 | 0.02 | 0.02 | .... | 98.10 | 1.19 | 0.0059 |
| 100 | .... | 2.95 | 0.05 | 0.11 | .... | 95.58 | 1.31 | 0.0067 |
| 90 | .... | 9.78 | 0.10 | 0.49 | .... | 88.28 | 1.35 | 0.0081 |
| 80 | .... | 32.18 | 0.17 | 1.85 | .... | 64.70 | 1.10 | 0.0123 |
| 70 | 0.03 | 61.83 | 0.20 | 4.72 | .... | 32.61 | 0.61 | 0.0274 |
| 60 | 0.03 | 81.22 | 0.15 | 7.69 | .... | 10.68 | 0.23 | 0.0935 |
| 50 | 0.12 | 86.78 | 0.10 | 10.17 | .... | 2.76 | 0.07 | 0.403 |
| 40 | 0.22 | 86.42 | 0.06 | 12.61 | .... | 0.67 | 0.02 | 1.84 |
| 30 | 0.35 | 84.26 | 0.03 | 15.18 | 0.01 | 0.16 | 0.01 | 8.63 |
| 20 | 0.59 | 81.24 | 0.02 | 18.10 | 0.01 | 0.04 | .... | 40.99 |
| 15 | 0.77 | 79.52 | 0.01 | 19.66 | 0.02 | 0.02 | .... | 89.66 |
| 11 | 0.94 | 78.02 | 0.01 | 20.99 | 0.03 | 0.01 | .... | 168.00 |
| 5 | 0.94 | 77.89 | 0.18 | 20.95 | 0.03 | 0.01 | .... | 405. |
| 0 | 0.93 | 77.08 | 1.20 | 20.75 | 0.03 | 0.01 | .... | 760. |

1. That at the surface of the earth the principal gases of the atmosphere and their respective volume percentages in dry air are:

| | | | |
|---|---|---|---|
| Nitrogen | 78.03 | Neon | 0.0012 |
| Oxygen | 20.99 | Helium | 0.0004 |
| Argon | 0.94 | Carbon dioxide | 0.03 |
| Hydrogen | 0.01 | | |

2. That at the surface of the earth water vapor supplies 1.2 per cent. of the total number of gas molecules present.

3. That the absolute humidity rapidly decreases, under the influence of lower temperatures, with increase of elevation, to a negligible amount at or below the level of 10 kilometres.

4. That the temperature decreases uniformly at the rate of 6° C. per kilometre from 11° C. at sea level to −55° C. at an elevation of 11 kilometres.

5. That beyond 11 kilometres above sea level the temperature remains constant at −55° C.

6. That up to the level of 11 kilometres the relative percentages of the several gases, excepting water vapor, remain constant—a result, of course, of vertical convection.

7. That above 11 kilometres, where the temperature changes but little with elevation, and where vertical convection, therefore, is practically absent, the several gases are distributed according to their respective molecular weights.

A number of atmospheric gases—neon, krypton, xenon, ozone, etc.—are omitted both from Table I and from its accompanying figure. This is because all these occur—in the lower atmosphere, at any rate—in quantities too small for graphical illustration in the same diagram and to the same scale as are the principal gases.

In using this diagram it should be distinctly remembered that it is supported by direct experimental observations only from the surface of the earth up to a level of about 30 kilometres, and that, while the extrapolated values are based upon apparently sound logic and not mere surmises, they necessarily become less and less certain with increase of elevation.

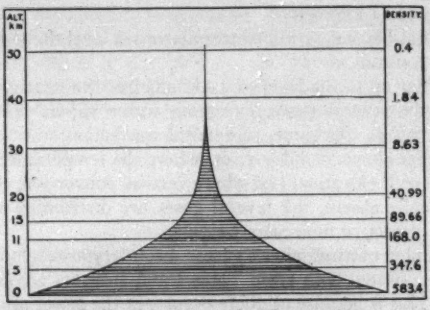
The table and the figure bring out a few points not generally realized. One of these is the fact that the total amount of argon in the atmosphere is much greater than the average total amount of water vapor. Another is the surprisingly small amount of water vapor, especially in view of the wonderful things it does,

and of its vital importance to life of every kind. There may also be a litfle surprise that, according to calculation, the percentage of water vapor reaches a certain maximum at an elevation of 70 to 80 kilometres, where it is, roughly, twenty-fold what it is at, say, 11 kilometres. This, however, does not mean that the total amount of water vapor increases with elevation, but that it decreases less rapidly than do the heavier constituents, and more rapidly than the two lighter ones, hydrogen and helium.

### DENSITY OF THE ATMOSPHERE.

Fig. 18, though serving the useful purpose of graphically representing the percentage distribution of the several gases of the atmosphere, nevertheless, is likely to be misleading in respect to

FIG. 19.




Density of the atmosphere at different levels.

their combined density, especially at great elevations. This latter information is shown by Fig. 19, in which the width at every altitude is proportional, approximately, to the corresponding atmospheric density, or at least to as great an elevation, about 40 kilometres, as the size of the figure will permit. Indeed, the density decreases so rapidly with increase of elevation that if at the level of 140 kilometres it is represented by a line only one-fourth of a millimetre long, then at sea level, taking into account difference in temperature and in composition, it would require for its full representation to the same scale a line whose length is, roughly, 600 metres. Obviously, therefore, the density of the atmosphere throughout its known range of, say, 250 kilometres cannot be graphically represented on any convenient scale.

## CHAPTER VI.

### INSOLATION.

THE temperature variations of the atmosphere, both as to time and to place, and also the actual average temperature for any given locality, all obviously are of the utmost importance within themselves, and of equal importance indirectly through such meteorological elements as humidity, precipitation, wind direction, wind velocity, and nearly everything else that contributes to the sum-total of both weather and climate. Hence it is imperative that in any general discussion of meteorology some consideration be given to the question of the source, or sources, of the heat energy necessary to these conditions, where it is delivered, and how distributed.

A little heat is given to the surface of the earth and the atmosphere surrounding it by conduction from the heated interior, a little as a result of certain chemical changes, some from tidal action, and another small amount by the absorption of stellar and lunar radiation. But the sum-total of all these several amounts is so small in comparison to that which results from the absorption of solar radiation that for even a close approximation to the total amount of thermal energy given to the atmosphere it is sufficient to consider the sun as its only source.

The rate at which heat is delivered to the earth from the sun depends upon:

*a*. The solar output of radiation.
*b*. Distance from the sun.
*c*. Inclination of the rays to the plane of the horizon, or solar elevation.
*d*. Transmission and absorption.

These factors, then, determine the earth's heat income, and will be considered *seriatim*. How this heat is conserved, distributed, and expended also are important problems, which will be taken up later.

### SOLAR OUTPUT OF RADIATION.

There is no *a priori* reason for assuming that the total output of radiation from the sun must remain strictly constant from age to age, from year to year, or even day to day. Neither is there any known *a priori* reason for supposing the solar radiation

must greatly vary, either periodically or irregularly. Hence it is distinctly a subject for continuous and careful observation, and this sort of observation is already well begun. Beginning with the summer of 1905, Messrs. Abbot and Fowle, of the Astrophysical Observatory of the Smithsonian Institution, and others working with them, have made numerous determinations of the solar constant, or intensity of the solar radiation as received at the outer surface of the atmosphere. Many of these observations were made on consecutive days, especially those obtained on Mount Wilson, California, and show irregular changes both as to time and quantity, changes often amounting to several per cent. in from five to ten days. In general, the observed values of the solar constant varied from one extreme to the other gradually and not by jumps. Besides, observations taken simultaneously, or at least on the same day, at stations so widely separated as Mount Wilson, California, and Bassour, Algeria, gave values that varied substantially together. "Hence," they say, "the most probable conclusion is that the sun actually varies from day to day in its output of radiation within limits of from five to ten per cent. in quantity and in irregular periods of from five to ten days."

The solar variations of even these short periods seem to produce noticeable weather effects,[18] while a change of, say, five per cent. in the solar constant, if long continued, obviously would be a matter of very great climatic importance. A five per cent. increase in the amount of radiation received means, of course, a correspondingly higher temperature equilibrium and, when that is established, a like increase in the amount of radiation that must somehow be sent out to space. An increase in temperature would, among other things, increase the cloudiness to some extent and therefore the amount of solar radiation directly reflected, but probably the chief increase of the outgoing radiation would be due to the greater temperature of the earth and the atmosphere. Suppose the terrestrial radiation to be increased by four per cent., roughly the amount that might be expected from a long-continued five per cent. increase of solar radiation. Then, since the effective absolute temperature of the earth as a full radiator is approximately 260° C.,[19] it follows, from the fourth power law, that

[18] Clayton, Smithsonian Miscellaneous Collections, **68**, No. 3, 1917.

[19] Abbot and Fowle, *Annals Astrophys. Obs. Smithsonian Institution*, **2**, p. 175 (1908).

the effective temperature increase, essential to this four per cent. greater terrestrial output of radiation, would be 2.6° C., an amount that, if continued for a number of years, would be very important. But, as already stated, the observed periods of solar variations, while irregular, appear always to be short, in fact so short as to produce only much smaller variations from the average temperature.

There is, however, some evidence that in addition to these short period changes there are also other changes of the solar constant coincident in period and time with the sunspot variation, and which therefore go through a complete cycle in about 11 years. The evidence in favor of this 11-year cyclic change is not conclusive, but it is found both in the relative pyrheliometric values and in the absolute determinations of the solar constant. Both indicate that the solar constant may be, roughly, two per cent. greater at the times of sunspot maxima than at the times of sunspot minima. This indicated change probably is in the same sense that most persons would anticipate from the fact that the solar surface is most agitated at the times of spot maxima. Nevertheless, it apparently is in direct conflict with the conclusion, supported by much statistical evidence, that the atmosphere as a whole is slightly warmer at the times of spot minima than at spot maxima. There is, however, a logical way out of the paradox which will be given later.

### DISTANCE FROM THE SUN.

If the apparent disk of the sun radiated equally all over, it would be strictly accurate to say that the intensity of its energy received at any particular point is directly proportional to the solid angle subtended by it at that point. But it does not radiate equally from all parts, either in amount or kind. The quantity of radiation per unit area of the apparent solar disk decreases from centre to circumference, while at the same time the spectral region of maximum intensity gradually shifts to longer and longer wave-lengths. Hence the total insolation at a given point cannot be rigidly proportional to the solid angle subtended. However, this departure from exact proportionality must in most cases be wholly negligible. Besides, the size of the solid angle subtended by the sun at the surface of the earth is so small that but little error would be made in problems of total radiation by re-

garding this angle as strictly zero and therefore applying without correction the law of inverse squares.

At aphelion the distance of the earth from the sun is, roughly, 3·3 per cent. greater than at perihelion. Hence the solar constant at perihelion, other things being equal, must be approximately 6.6 per cent. greater than at aphelion. And, since the earth may be regarded as a full radiator at about 260° C. absolute, it follows that its effective temperature must be greater when a maximum than when a minimum by about 1.6 per cent. of the average value, or, roughly, by 4° C.

All these calculations assume complete equilibrium between radiation and absorption, and, while there necessarily is some lag, an approach to equilibrium, as a little calculation will show, probably comes much sooner than one might suppose to be the case. Hence northern winters are not only shorter but also warmer than they would be if they occurred at times of aphelion instead of, as they do, at times of perihelion; while the winters of the southern hemisphere, during which the earth is farthest removed from the sun, have now a maximum both of duration and severity.

Notwithstanding—really, because of—the marked difference between the perihelion and aphelion intensities of the solar radiation at the limit of the atmosphere, it is easy to show that the total amount of insolation on the earth as a whole is constant per constant angular distance along its orbit; and that each hemisphere, regardless of the perihelion phase, or exact date on which perihelion occurs, receives during the course of a whole year exactly the same amount of solar radiation as does the other. This is shown as follows:

Let $R$ be the solar distance, $d\theta$ the angle at the sun swept over by the earth in the time $dt$. Then, from the law of equal areas,

$$R^2 d\theta = C dt,$$

in which $C$ is a constant.

Also, if $dQ$ is the amount of solar energy incident upon the earth in the time $dt$,

$$dQ = \frac{I}{R^2}\, dt$$

in which $I$ is the solar constant at unit solar distance. Hence

$$dQ = \frac{I}{C}\, d\theta,$$

or the energy received by the earth from the sun, assuming the

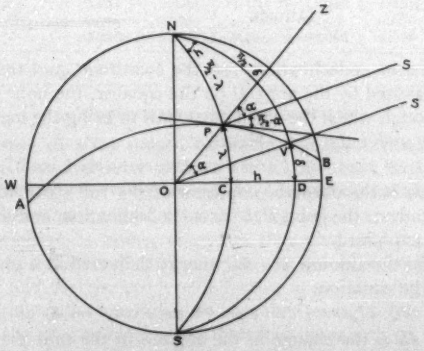
solar output to be constant, is directly proportional to the angular distance between the initial and final radii vectores. Since the direction of the earth's axis is practically fixed in space, it follows that, to the same degree of approximation, each hemisphere must be inclined toward or from the sun over exactly one-half the angular orbit, and hence that the total yearly amount of heat received by one hemisphere is the same as that received by the other, and also that the earth as a whole gets precisely the same amount of radiant energy during the aphelion half of its orbit that it does during the perihelion half—what it loses in distance it exactly makes up in time.

It must not be supposed that this equality of heat supply means equality of world temperatures. Indeed, it means quite the reverse, for the equal quantities are delivered in unequal times; the time being longest and therefore the world temperature the lowest, except in so far as there may be a lag, during aphelion, and shortest with highest temperature, as previously explained, during perihelion.

### SOLAR ALTITUDE.

Leaving out, for the present, all questions of atmospheric absorption, it is obvious that the intensity of insolation is directly proportional to the sine of the angle of solar altitude, or to the

FIG. 20.

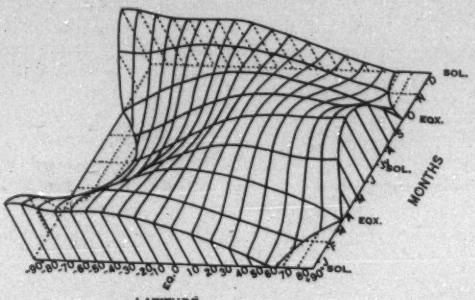



Relation of insolation to latitude, declination, and hour angle.

cosine of the sun's zenith distance. But neither of these angles is directly known, and therefore can be expressed only in terms of those that are known. Each, however, is a function of latitude, of the time of day, expressible as an hour angle, and solar declination, as will be explained by the aid of Fig. 20.

Let $P$ be the point of observation, with its zenith at $Z$, and let the sun be off in the direction $OS$ or $PS$. Clearly, then, the plane of $OZ$ and $OS$ intersects the surface of the earth in a great circle, and the angle $ZOS$, measured by the arc $PV$ of this circle, is equal to the sun's zenith distance. But in the spherical triangle $NPV$ it is obvious that the arc $NV$, $V$ being directly under

FIG. 21.




Relation of insolation to season and latitude.

the sun, is the codeclination, $NP$ the colatitude, and the angle $h$ at $N$, measured by the arc $CD$ on the equator, the hour angle, or angle through which the earth must turn to bring the meridian of $P$ directly under the sun. Hence

$$I_n = I \cos \alpha = I \ (\sin \phi \sin \delta + \cos \phi \cos \delta \cos h),$$

in which $I_n$ is the normal component of the full solar intensity $I$, $\varphi$ the latitude of the point $P$, $\delta$ the solar declination, and $h$ the hour angle, as explained.

To find the amount of solar energy delivered at a given point we have the equation,

$$dQ = I_n dt = I \ (\sin \varphi \sin \delta + \cos \varphi \cos \delta \cos h) \ dh$$

in which $dh$ is the change in the angle $h$ in the time $dt$. To obtain the total energy delivered per unit area in the course of a

day we may consider $I$ and $\delta$ constant for that time, and therefore write,

$$Q = 2I\ (\sin\varphi \sin\delta\, H + \cos\varphi \cos\delta \sin H)$$

in which $H$ is the hour angle between noon and sunrise or sunset.

$H$ obviously is a function of $\varphi$ and $\delta$. Thus at sunrise, say, $a = \frac{2}{\pi}$. Hence,

$$\cos a = 0 = \sin\varphi \sin\delta + \cos\varphi \cos\delta \cos H$$

and

$$\cos H = -\tan\varphi \tan\delta.$$

Now $\varphi$, the latitude of the place in question, is known, and $\delta$, the solar declination for any given day, is obtainable from an ephemeris. Hence, assuming a constant output of solar energy and allowing for variations in solar distance, the relative per diem amounts of insolation delivered to the earth (outer atmosphere) at different latitudes and different times may readily be computed. A few of these values, in terms of the total insolation received at the equator on the day of the vernal equinox, are given in the following table, and the complete data for all seasons and all latitudes in Fig. 21, both of which are copied from Davis's "Elementary Meteorology," Ginn & Co.:

| Latitude..... | 0° | +20° | +40° | +60° | +90° | −90° |
|---|---|---|---|---|---|---|
| March 20..... | 1.000 | 0.934 | 0.763 | 0.499 | 0.000 | 0.000 |
| June 21..... | 0.881 | 1.040 | 1.103 | 1.090 | 1.202 | 0.000 |
| September 22..... | 0.984 | 0.938 | 0.760 | 0.499 | 0.000 | 0.000 |
| December 21..... | 0.942 | 0.679 | 0.352 | 0.000 | 0.000 | 1.284 |
| Annual total.... | 347 | 329 | 274 | 197 | 143 | 143 |

### TRANSMISSION AND ABSORPTION.

The rate of solar output of energy, distance from the sun, length of day, and solar altitude are all, as above explained, of vital importance in determining the amount of radiant energy delivered to unit horizontal area during any interval of time—any consecutive 24 hours, say. But they give only the quantity of insolation delivered, and not the amount of energy actually absorbed and thereby rendered effective in maintaining temperature. This smaller quantity, the absorbed energy, depends upon not only the total insolation and therefore upon each of the above factors, but also upon at least two others; namely, reflection and

scattering. Thus it is obvious that all that solar radiation which is reflected back to space, whether by clouds or by the surface of the earth, is immediately and completely lost, so far as heating the atmosphere is concerned, and that the same is also true of that smaller portion lost through the process of scattering, whether by dust particles or by air molecules.

The total loss of insolation by these two processes, reflection and scattering, amounts, according to Abbot and Fowle,[20] to about 37 per cent. for the whole earth. In other words, more than one-third of all the energy delivered to the earth is unused—merely scattered to space.

When solar radiation is minutely analyzed spectrally it exhibits thousands of irregularities in the wave-length distribution of energy that were present even before the outer atmosphere was reached. The minima, indicating strong absorption in the solar atmosphere, constitute the well-known Fraunhofer lines.

In addition to the vast number of intensity deficiencies, absorption or Fraunhofer lines, as they are called, inherent in solar radiation, there are also many similar deficiencies resulting from its passage through the earth's atmosphere. These are caused by oxygen, carbon dioxide, water vapor, and ozone, and possibly even by other substances. Three of these, carbon dioxide, water vapor, and ozone, are also strongly absorptive of the long wave-length earth radiation. Oxygen and water vapor have many exceedingly restricted regions of absorption—so restricted, indeed, that in mere appearance they are indistinguishable from the narrow Fraunhofer lines. But in addition to these numerous narrow lines there are also a number of broad absorption bands, certainly of water vapor, ozone, and carbon dioxide. Oxygen, too, seems to have a broad absorption band in the region of exceedingly short wave-lengths. It is possible that many, if not all, of the bands are simply aggregates of large numbers of individual lines, but this is not known to be true of any of them.

Whatever the actual process of absorption, it is certain that to within observational errors the amount of energy absorbed increases arithmetically with the intensity of the incident radiation and geometrically with the quantity of the absorbing material passed through, provided it is all under the same physical condition. Thus if $I_0$ is the initial intensity of a beam of parallel

[20] *Annals Astrophys. Obs. Smithsonian Institution*, 2, p. 163.

radiation, and $aI_0$ its intensity after passing normally through a homogeneous layer of absorbing material of unit thickness, then its intensity after traversing a distance of $m$ units in the same material is given by the equation,

$$I_m = I_0 a^m.$$

In the case, also, of scattering of radiation the extinction progresses according to the same laws that apply to absorption. That is to say, it is always a constant fraction of the remaining radiation that gets through a unit quantity of the scattering material.

The coefficients both of direct absorption and of extinction by scattering are radically different for radiations of different wave-lengths. But if $I_0$ is the initial intensity of the radiation of a given wave-length and $aI_0$ its intensity after it has passed normally through a layer of absorbing material of unit thickness, then after normal transmission through layers $m$ and $n$ units thick respectively,

$$I_m = I_0 a^m, \text{ and } I_n = I_0 a^n$$

Hence,

$$a = \left(\frac{I_m}{I_n}\right)^{\frac{1}{m-n}}, \text{ and } I_0 = I_m \left(\frac{I_m}{I_n}\right)^{\frac{m}{n-m}}$$

Now, in the case of the atmosphere, while in a vertical direction there is neither homogeneity in dust content nor in density, there is approximate horizontal homogeneity in respect to both conditions. Hence by observing the sun at different angles of elevation a considerable range in the ratio between $m$ and $n$ can be obtained for the atmosphere as a whole.

For simplicity it is desirable to take $n = 2m$, from which,

$$I_0 = \frac{I_m}{I_{2m}} \text{ (equation of Bouguer).}$$

As both $I_m$ and $I_n$ are measurable, anywhere at the surface of the earth, $I_0$, or the intensity of the radiation outside the atmosphere, is at once determined to approximately the same degree of accuracy. The equation, however, is accurate only for monochromatic radiation. If applied to the whole, or even any considerable part, of the solar radiation as a unit the value thus obtained for the intensity of the initial radiation will be too small, as Langley showed long ago. This can be seen as follows:

Let the intensities of the several monochromatic radiations be $A_0$, $B_0$, $C_0$, etc., and their respective coefficients of transmission $a$, $b$, $c$, etc. Then their combined residual intensities after passing through the thickness $m$ and $2m$ of the absorbing medium will be, respectively,

$$A_0a^m+B_0b^m+C_0c^m+, \text{ etc.} = R_m$$

and

$$A_0a^{2m}+B_0b^{2m}+C_0c^{2m}+, \text{ etc.} = R_{2m}$$

Hence the initial intensity, as computed by the Bouguer equation, is

$$R_0 = \frac{R^2_m}{R_{2m}}$$

But the difference between the actual and the computed initial intensity is

$$A_0+B_0+C_0+, \text{ etc.} - R_0 =$$

$$A_0+B_0+C_0+ \text{ etc.} - \frac{(A_0a^m+B_0b^m+C_0c^m+\text{etc.})^2}{A_0a^{2m}+B_0b^{2m}+C_0c^{2m}+\text{etc.}} =$$

$$\frac{A_0B_0(a^m-b^m)^2+A_0C_0(a^m-c^m)^2+\ldots\ldots+B_0C_0(b^m-C^m)^2+\text{etc.}}{A_0a^{2m}+B_0b^{2m}+C_0c^{2m}+\text{etc.}}$$

An occasional term in the numerator of this final fraction may reduce to zero, since possibly $a = k$, $c = l$, etc., but in general no two of the coefficients, $a$, $b$, $c$, etc., are equal to each other. Hence every term in the numerator, except the few zero ones, if such exist, and consequently the fraction as a whole, is both real and positive. The Bouguer equation, therefore, when applied to complex radiation, always gives too small a value for the initial intensity.

Clearly, then, to determine to the highest degree of accuracy the intensity of the radiation reaching the outer atmosphere (that is, the amount per unit normal surface per unit time) it is necessary first to analyze it into its spectroscopic components and then either to determine the initial intensity of each or else to adopt some equivalent process. The direct method of measuring the energy in each small spectral range would be very tedious, and, besides, would involve a difficult instrumental standardization, hence the following method has been found more convenient:

1. Analyze the insolation and obtain, with the bolometer, the relative distribution of energy through the spectrum for different solar altitudes but, as nearly as possible, constant sky conditions.

In each case the value of $m$, the air mass as it is called, is proportional to the secant of the solar zenith distance. Hence when the solar altitudes at which the bolograms were taken are known, the ratios of the corresponding $m$'s, being the ratio of the respective zenith distance secants, are also known.

2. Measure with a pyrheliometer the rate at which solar energy, exclusive of sky radiation, is delivered per unit normal area during the same time that one of the bolograms was being obtained.

3. Extrapolate, according to the Bouguer equation, each portion of the bolograms to zero atmosphere and thus obtain the initial bologram, or energy distribution through the solar spectrum outside the atmosphere.

4. Measure the areas between the base line, corresponding to zero insolation, and the two bolograms, the extrapolated and the one corresponding to the pyrheliometric reading.

5. From these areas, $A_0$ and $A$, respectively, and the observed solar intensity $I$, compute $I_0$, the intensity of solar radiation outside the atmosphere, by the equation,

$$I_0 = I\frac{A_0}{A}$$

When expressed in terms of gram-calories per square centimetre normal surface per minute the average value of $I_0$, known in this form as the solar constant, is about 1.93.[21]

As stated above, careful estimates show that about 37 per cent. of this radiant energy is wholly lost to the earth, leaving only some 63 per cent. directly absorbed in roughly equal amounts by the earth and the atmosphere. But since the reflecting power of the earth is small, and since the air usually is nearly opaque to terrestrial radiation, it follows that approximately 60 per cent. of the incident solar energy ultimately heats the atmosphere.

The more conspicuous notches in the bolometric curve coincide with water vapor absorption bands, from which it is inferred that most of the direct absorption of solar energy in the atmosphere is due to water vapor. All these bands, however, are of longer wave-length than the region of maximum intensity in the solar spectrum, as are also the absorption bands of carbon dioxide and the stronger bands of ozone. Nitrogen and argon have no

[21] Abbot and Fowle, *Annals Astrophys. Obs. Smithsonian Institution*, 3, p. 134 (1913).

known absorption bands, while oxygen, the only other important constituent of the atmosphere, has only one, and that in the extreme ultraviolet or Schumann region. Further, the general absorption of all three is so feeble that, to a first approximation, it may be regarded as wholly negligible. Hence atmospheric absorption of radiation, whether solar or terrestrial, obviously is due almost wholly to water vapor, carbon dioxide, and ozone; and, since the approximate amount of carbon dioxide in the atmosphere is always known and that of water vapor at least often determinable, it frequently is possible, by the aid of laboratory data, to know roughly the actual absorption in any portion of the spectrum due to these two substances, either singly or jointly.

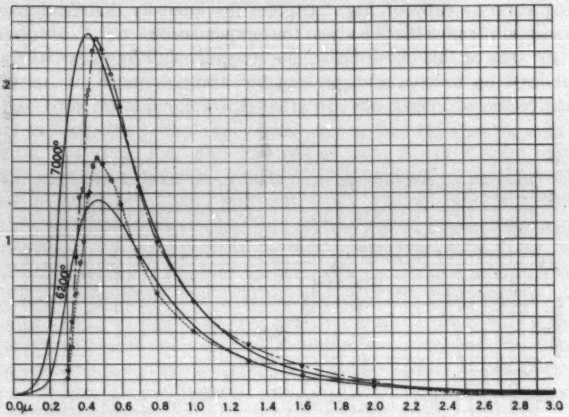
The magnitude of the ozone effect, however, is always uncertain because the quantity of this gas in the atmosphere is not known. In the presence of moisture and at ordinary temperatures it soon reverts to ordinary oxygen—a sufficient reason, perhaps, why only traces of it are found in the lower atmosphere. In the high atmosphere, on the other hand, where there must be very little moisture and where the temperature in mid-latitudes is about $-55°$ C., and even lower in the tropics, it obviously is far more stable. Hence, since extreme ultraviolet radiation, such as there is every reason to believe is emitted by the sun, on passing through cold dry oxygen converts much of it into ozone, it appears exceedingly probable that this substance must exist to appreciable amounts in the higher portions of the atmosphere. Indeed, this probability may be regarded as reduced very nearly to a certainty by Ångström's [22] discovery of two solar spectrum bands coincident with ozone absorptions at about $\lambda 4.7\mu$ and $\lambda 9.5\mu$, respectively; and by an investigation by Fabry and Buisson [23] which shows that the observed limit of the solar spectrum appears to be fixed by that ozone band of extraordinary absorptive power whose maximum occurs at about $\lambda 0.254\mu$. Presumably, then, there is sufficient ozone in the atmosphere to be of importance with respect to both the incoming and outgoing radiation.

The form of the solar energy spectrum curve outside the atmosphere as determined by Abbot and Fowle and its comparison with "black-body" curves at 6200° and 7000° absolute C. are given by Fig. 22, a copy of Fig. 29, vol. iii, *Annals of the*

[22] *Arkiv. för Matematik, Astronomi och Fysik.*, 1. p. 395 (1914).
[23] *Journal de physique* (5), 3, p. 196 (1913).

*Astrophysical Observatory of the Smithsonian Institution.* The curve of terrestrial radiation intensities, on the other hand, is not known, but it obviously must be within that of a full radiator at

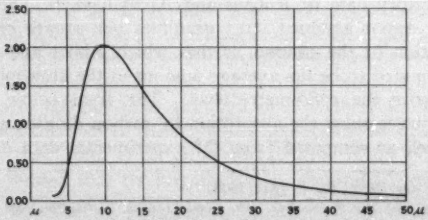
FIG. 22.




Comparison of solar and "black-body" energy distribution.

the earth's temperature, but close to it, because of the universal presence of the highly absorptive substances, water vapor, especially, carbon dioxide, and ozone. That is, it must be within, but close to, the black-body curve for 287.2° C. absolute, as shown

FIG. 23.

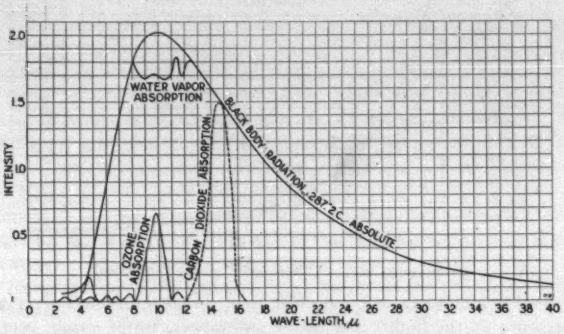



"Black-body" radiation at earth temperature.

in Fig. 23, copied from Plate XX, vol. ii, *Annals of the Astrophysical Observatory of the Smithsonian Institution* (Abbot and Fowle).

The absorptions of earth radiation by water vapor, carbon dioxide, and ozone are shown in Fig. 24. The outer or enveloping curve, a copy of Fig. 23, gives the intensity distribution of radiation from a black body at the temperature 287.2° C. absolute. The area of this curve below the irregular full line near its top, at least up to 20μ, and, presumably, through much, if not all, the region of longer wave-lengths, shows the absorption of earth

FIG. 24.




Water vapor, carbon dioxide, and ozone absorption.

radiation by a column of 1.13 grammes of water vapor per square centimetre cross-section, as computed by Bouguer's equation from the laboratory data of Rubens and Aschkinass.[24] The amount of water vapor assumed, 1.13 grammes per square centimetre cross-section of the column, is that which Abbot and Fowle[25] have computed to be the average amount in the atmosphere as a whole above the 1780-metre level. The areas below the two broken curves show the absorption by carbon dioxide above the same level, as computed from the experimental data of Schae-

[24] *Ann. der Phys.*, **64**, p. 584 (1898).

[25] *Annals of the Astrophys. Obs. Smithsonian Institution*, vol. ii, p. 168 (1908).

fer,[26] and Rubens and Aschkinass.[27] Finally, the area below the dotted line gives some idea of the absorption of earth radiation by ozone, computed, after making certain assumptions explained below, from the observations of Ladenburg and Lehmann.[28] The amount of the ozone absorption, however, is uncertain, as implied, for several reasons: (*a*) Laboratory measurements have not extended beyond 12$\mu$. (*b*) While Ladenburg and Lehmann give the length of the absorbing column used, one metre, and describe minutely their ingenious manometer, they do not state the actual pressures at which their data were obtained. But as their ozone was nearly pure, and as they refer to the color of the gas at 50 mm. and 200 to 300 mm., it would seem that they used the equivalent, roughly, of a column 30 centimetres long at, say, 15° C. and 760 mm. (*c*) The amount of ozone in the atmosphere is not known. Pring,[29] who appears to have done the most careful work on this subject, estimates it to be the equivalent of a layer of the pure gas 4.2 centimetres thick at normal temperature and pressure. Hence the assumptions referred to above were (1) that the ozone in the absorption tube was the equivalent of a column 30 centimetres long, and (2) that the ozone in the atmosphere is equivalent to a layer whose thickness is only 4.2 centimetres, each at atmospheric pressure and room temperature.

It appears, then, as shown by Fig. 24, that the absorption of earth radiation by water vapor is nearly perfect, even beyond the level of one to two kilometres; that neither at this level nor, perhaps, at any other (consult Fig. 18 and its accompanying table for probable distribution of carbon dioxide and water vapor) does the carbon dioxide appreciably affect the amount of absorp- into—already complete (through the presence of water vapor) in the regions of its bands; and that, since ozone absorption is very strong where that of water vapor is weakest and imperfect and earth radiation at its maximum, the presence of this gas in the atmosphere has a slight heat-conserving or warming effect.

It is also obvious that, although each of these substances is an effective absorber in the region of appreciable to strong solar radiation, their joint effect on earth radiation is far greater, so much so, indeed, that for low levels it is practically complete.

[26] *Ann. der Phys.*, 16, p. 93 (1905).
[27] *Loc. cit.*
[28] *Ann. der Phys.*, 21, p. 305 (1906).
[29] *Proc. Roy. Soc., A*, vol. 90, p. 204 (1914).

### SURFACE TEMPERATURES AND ABSORBING GASES.

The radiation from a particle of water vapor, or any other substance in or of the atmosphere, clearly is equal in all directions. Hence the amount of radiant energy incident on the surface of the earth and the resulting temperature are generally different from what they would be in the absence of any such absorbing and radiating medium. During the night, when there is no incoming radiation to consider, the process of absorption and radiation by the constituents of the atmosphere manifestly checks the rate of surface cooling, and thereby insures higher night temperatures than otherwise would obtain. Whether this process also increases day temperatures is not so obvious. It does, as the following argument will show, when and only when the substance involved, whether the ozone shell, presumably in the isothermal region, the water vapor shell of the lower atmosphere, or any other such shell, is more absorptive of the outgoing terrestrial radiation than of the incoming solar radiation.

The numerical solution of the problem as applied to any one of these shells is complicated by the alternation between night and day; by constant changes in the solar inclination; by reflection; and probably by many other conditions of importance. However, since the coefficient of absorption is independent of intensity of radiation, it is possible to obtain an approximate evaluation of the temperature effect due to any given absorbing layer or shell.

Let $I$ be the average intensity of the normal component of the absorbed portion of solar radiation; that is, assuming, as already explained, that 37 per cent. of the incident solar energy is wholly lost by reflection, and representing the solar intensity outside the atmosphere by $I_0$, then, dividing the cross-section of the beam, multiplied by its effectiveness, by the area over which it is distributed,

$$I = \frac{0.63 I_0 \pi R^2}{4\pi R^2} = 0.16\ I_0, \text{ about,}$$

in which $R$ is the effective radius of the earth as an intercepter of incoming radiation.

Also let $aI$ be the average intensity of solar energy, including both the direct and the reflected, absorbed by the outermost shell, say, or by the ozone of the upper atmosphere. Half this absorbed

energy is radiated to space and half to the earth, including the lower atmosphere.

The earth, which for convenience may be considered initially cold, now receives radiation of the average intensity $(1-a)\ I$ from the sun, and of the intensity $\frac{a}{2}\ I$ from the absorbing layer under consideration. Together these amount to $I\ (1-\frac{a}{2})$.

After a time the earth will return an equal average radiation, but of very different spectral distribution. Let $b\ I\ (1-\frac{a}{2})$ be the part of this long-wave earth radiation absorbed by the layer in question. As before, one half, or $\frac{b}{2}\ I\ (1-\frac{a}{2})$, will be radiated back to the earth, there absorbed, because of its long wave-length, and again sent out. The next amount returned by the shell is $\left(\frac{b}{2}\right)^2 I\ (1-\frac{a}{2})$, and so on infinitely.

Hence the total average intensity, $I_e$, of the radiation reaching the earth and lower atmosphere is given by the equation,

$$I_e = I\left\{1-\frac{a}{2}\right\}\left\{1+\frac{b}{2}+\left(\frac{b}{2}\right)^2+\ldots\ldots+\left(\frac{b}{2}\right)^\infty\right\}$$

$$= I\left\{1+K(b-a)\right\}-\frac{a}{2}\left(\frac{b}{2}\right)^\infty$$

$$= I\left\{1+K(b-a)\right\}, \text{ since } b \text{ cannot exceed unity,}$$

in which

$$K=\frac{1}{2}\left\{1+\frac{b}{2}+\left(\frac{b}{2}\right)^2+\ldots\ldots+\left(\frac{b}{2}\right)^\infty\right\}$$

Now, $b$ is positive and therefore $K$ is also positive. Hence

$$I\left\{1+K(b-a)\right\}\gtreqless I$$

according as

$$b \gtreqless a$$

That is, the total amount of radiation reaching the earth is increased, unchanged, or decreased by the presence of an absorbing shell according as its coefficient of absorption of terrestrial radiation is greater than, equal to, or less than its coefficient of absorption of solar radiation. But water vapor, carbon dioxide, and ozone are all more absorptive of earth radiation than of the comparatively short wave-length solar energy, and therefore each,

but water vapor especially, keeps the average temperature higher than it otherwise would be.

Suppose $b = 20$ per cent. and $a = 2$ per cent., then,

$$I\left\{1 + K(b-a)\right\} = 1.1I, \text{ about.}$$

That is, the incoming radiation, and hence also the outgoing radiation, is increased 10 per cent. over what it would be if such an absorbing layer did not exist. But as the earth, largely because of its water vapor, radiates substantially as a black body, or in proportion to the fourth power of the absolute temperature, it follows that a 10 per cent. increase of radiation implies approximately a 2.5 per cent. increase of the absolute temperature. In other words, an absorbing shell with the properties assumed, properties that possibly are of the same order of magnitude as those of the existing ozone in the upper atmosphere, would maintain the average temperature of the earth about 7° C. higher than it otherwise would be.

Any increase, then, in the amount of ozone, or other similar absorbing material, in the outer atmosphere must more or less increase the average temperature of the earth. Hence variations in the output from the sun of the ozonizing or very short wavelength radiation presumably would alter the ozone content of the upper air and through it, as above explained, the average temperature of the earth. Other things being equal, it would seem that there should be a maximum of this extreme ultraviolet radiation and, consequently, maximum average temperature at the time of a sunspot minimum when the solar atmosphere is comparatively clear, as indicated by a minimum corona; and a minimum, with minimum average temperature, at the time of a spot maximum when the "dustiness" of the solar atmosphere, as shown by a maximum corona, is very great. Even if the solar constant should be a little greater at the time of a spot maximum than at a spot minimum, the above variation of ozone, if it occurs, might lead to the paradoxical concurrence of maximum average temperature with minimum average insolation and minimum average temperature with maximum average insolation.

*(To be continued.)*

# MODERN DYNAMO ELECTRIC MACHINERY.*

BY

ALEXANDER GRAY, M. Sc.,

Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

## TURBO-ALTERNATORS.

The history [17] of the development of the turbo-alternator begins about 1889, when a 75-kilowatt machine was built by the Parsons Company to operate at 4800 revolutions per minute. Some of the other early turbo-alternators developed by this company were: [18]

| Date | Kilowatts | R.P.M. | Poles | Remarks |
|---|---|---|---|---|
| 1889 | 75 | 4800 | 2 | Rotating armature type with surface ventilation. |
| 1891 | 150 | 4800 | 2 | Rotating armature with radial ducts fed by axial holes. |
| 1894 | 350 | 3000 | 4 | Rotating armature with axial ducts and a fan at one end. |

It is of interest to note that, as early as 1894, Parsons had used both radial and axial ventilation; even to-day there is much controversy as to which is the most satisfactory for modern turbo-alternators.

By 1899 the output had become so large and the voltage so high that it was no longer considered desirable to use the rotating armature type of machine, and so the rotating field type gradually won favor. The Brown Boveri Company, from the start in 1901, have built the smooth drum type of rotor, shown in Fig. 57, their purpose being "to subdivide the field winding into a number of slots with a view to distributing the centrifugal force of the winding, the whole of the field iron being thereby brought into close proximity with the armature surface and the space between the usual salient polepieces being utilized.

Up until 1905 two methods were used to cool these machines. In the older method standard slow-speed practice was followed,

* Continued from page 226, August issue.

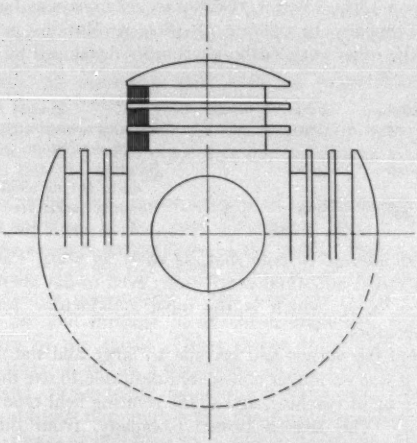
[17] "The Engineering Evolution of Electrical Apparatus," Lamme, *Electric Journal*, vol. ii, p. 221, 1914.

[18] "High-speed Electrical Machinery," Storey and Law, *Journal of the Institution of Electrical Engineers*, vol. 41, p. 286, 1908.

the air being stirred up around the machine and the exposed surface made as large as possible. In modern practice, however, the machine is totally enclosed so that it will operate quietly while air is forced through the machine and directed on the surfaces to be cooled.

In those days, also, there was much discussion as to the best type of turbo-rotor.[19] Some had salient poles as shown in Fig. 56, others were of the cylindrical drum type as shown in

FIG. 56.



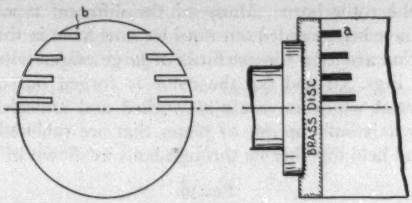
High-speed rotor with salient poles.

Figs. 57 and 58, some were built up out of laminations and others of 2½-inch disks mounted on a shaft, some were solid forgings and others were of cast steel. There was much argument as to the relative merits of the salient pole and of the cylindrical type of construction, and this subject was finally thrashed out in the discussion of a paper[20] by Miles Walker in 1910, by which time it had become apparent to designers of turbo-alternators of large output that the cylindrical type of rotor was

[19] "Steam Turbine Dynamos," Ellis, *Ibid.*, vol. 37, p. 305, 1906.

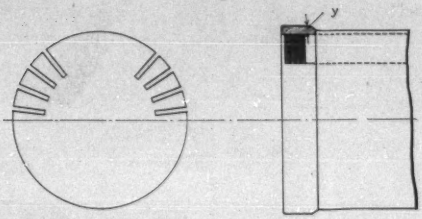
[20] "Design of Turbo Field Magnets for Alternate-current Generators," Walker, *Ibid.*, vol. 45, p. 319, 1910.

FIG. 57.



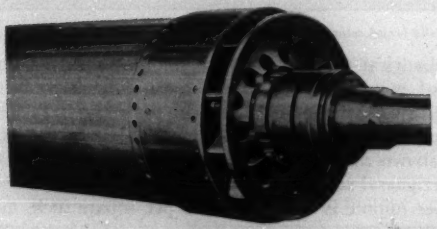

Cyllndrical type of rotor with parallel slots. In this type the end connections *a* are well supported, but the bending stress at *b* becomes excessive at high speeds.

FIG. 58.




Cylindrical type of rotor with radial slots. There is no bending force on the teeth, but the support for the end connections is not as good as in Fig. 57.

FIG. 58A



Part of the rotor of a 1250-kv.a., 3600-r.p.m. generator.

the more satisfactory because of the better utilization of the space in the rotor bore. Many of the different types of construction have been weeded out until we now have in this country only two that are used for machines of large output: in one case, shown in Figs. 59 and 60, the rotor is forged out of a solid block of steel which is carefully worked and annealed; in the other case it is built up out of plates that are rabbited into one another and held together by through bolts as shown in Fig. 61.[21]

FIG. 59.

Hydraulically forged rotor core and shaft for a 6250-kv.a., 3600-r.p.m. turbo-alternator.

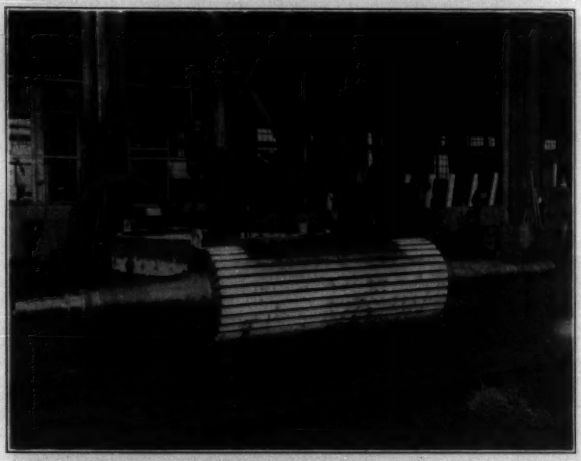
A cylindrical rotor with radial slots is shown in Fig. 62 in process of winding. One of the most difficult problems with this type of construction is to support the rotor end connections. They are generally held against centrifugal force by a retaining ring as shown in Fig. 58. The stress in such a ring rotating with a peripheral velocity of 23,000 feet per minute at 1800 revolutions per minute is 15,000 pounds per square inch, due to its

[21] "Some Difficulties of Design of High-speed Generators," Field, *Ibid.*, vol. 54, p. 65, 1915.

own weight, and, in order that the ring may support the end connections at 20 per cent. overspeed, it must be of high-grade steel, which material may be obtained in the form of a nickel chrome steel weldless ring with the following characteristics:

| | | |
|---|---|---|
| Ultimate stress | = | 120,000 pounds per square inch. |
| Elastic limit | = | 100,000 pounds per square inch. |
| Elongation | = | 18 per cent. on 2 inches. |
| Reduction in area | = | 50 per cent. |

FIG. 60.



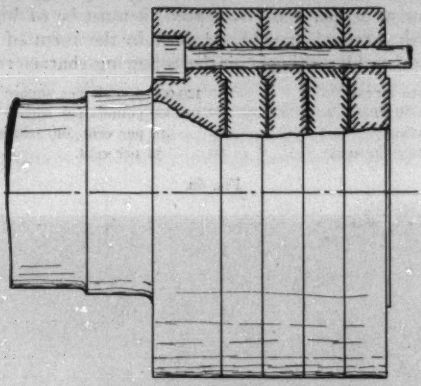
Rotor core of a 6250-kv.a., 3600-r.p.m. turbo-alternator.

It is true that by using steel for this purpose a magnetic shunt is placed between the poles, and the resulting leakage flux is limited only by the saturation of the material, so that the leakage factor would be large were it not for the fact that the poles are long and the useful flux per pole is large.

*Limitations in Modern Turbo-Alternators.*

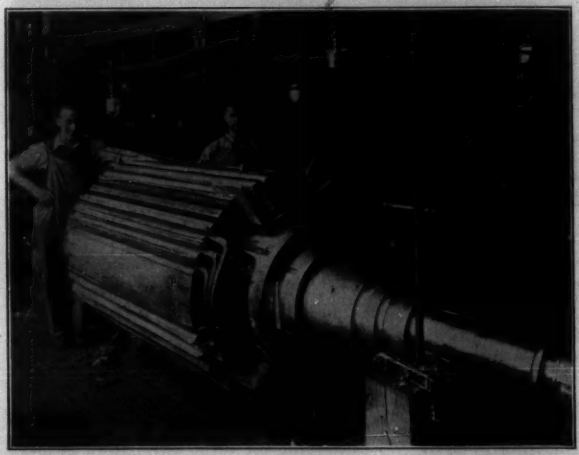
We have seen that the cylindrical type of rotor has proved by experience to be the most desirable for turbo-alternators of large output and high speed, and, in order to understand the develop-

FIG. 61.



Cylindrical rotor built up out of plates.

FIG. 62.



Rotor of a 12,500-kv.a., 1800-r.p.m., 60-cycle turbo-alternator.

ment that has taken place, we shall find the dimensions of a 60-cycle machine with an output of 30,000 kilovolt-ampères at 1800 revolutions per minute, and then show by how much the output would have to be reduced if the regulation and the permissible rise of temperature were as specified a few years ago.

*Maximum Permissible Diameter of Rotor.*—The subject of stresses in rotating disks that are loaded on the external periphery is very complex and is beyond the scope of this article.[22] Turbo-rotors have been built to run at 1800 revolutions per minute with a peripheral velocity of 24,000 feet per minute without the use of special steel, and, taking this as a suitable value, the diameter of the rotor for such a machine is 51 inches.

*Width of Rotor Winding Belt.*—It may be seen from Fig. 62

FIG. 63.

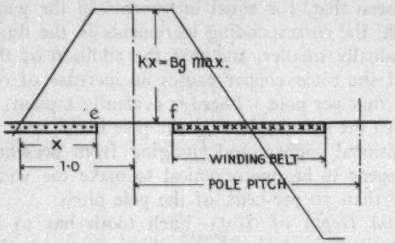
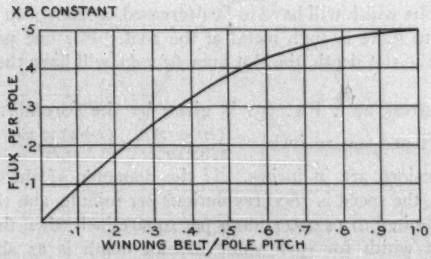



FIG. 64.




Effect of the width of the winding belt on the flux per pole.

[22] "Design and Construction of Steam Turbines," by H. M. Martin, published by Longmans, Green & Co., in 1913.

that the whole rotor surface is not utilized to carry the rotor winding; there is still room for two more slots per pole at $p$ and $q$ and for one more coil. It will be noted, however, that this coil would span only a small part of the pole pitch, so that the additional flux produced per pole would not be worth the cost of the additional copper.

In Fig. 63 let the rotor be wound uniformly over a belt of width $x$ and let the air-gap clearance be uniform; then the curve of flux distribution will be as shown, and

the flux density over the surface $ef = kx$

$$\text{the total flux per pole} = \text{a constant } \left[x\ (1-x) + \frac{x^2}{2}\right]$$

$$= \text{a constant } \left[x\ \left(1-\frac{x}{2}\right)\right]$$

This is the equation to the curve in Fig. 64, from which curve it may be seen that, for equal increments in the width of the winding belt, the corresponding increments in the flux per pole become gradually smaller, and that the addition of the last 30 per cent. of the rotor copper causes an increase of only 9 per cent. in the flux per pole. There is evidently a point, therefore, beyond which the gain in the flux per pole is not worth the price of the additional copper, and, judging from present practice, it would appear to be uneconomical to make the width of the belt greater than 70 per cent. of the pole pitch.

*Maximum Depth of Slot.*—Each tooth has to be strong enough to carry the centrifugal force due to its own weight and to that of the contents of one slot, so that if the depth of slot is increased its width will have to be decreased, as shown in Fig. 65, in order to leave enough metal at the root. For one particular value of the slot depth, the slot area $(s \times d)$ will have the largest value.

The stress at $t$, Fig. 65, is given by the formula: Stress in pounds per square inch $= \frac{(r1^3 - r2^3)}{21.5 \times 10^6 \times l} \times \frac{(t+s) \times 360}{2\pi r2}$ where the dimensions are in inches. If the diameter of the rotor is 51 inches, the speed is 1800 revolutions per minute, and the tooth stress is limited to 14,000 pounds per square inch; then the maximum slot width for each value of slot depth is as shown in Fig. 66; the variation of permissible slot area with slot depth is also shown, and in this particular case there is nothing to gain by using slots that are deeper than 7 inches.

*Number of Slots per Pole.*—Given that the rotor diameter is 51 inches, the winding belt covers 70 per cent. of the pole pitch, and the slot depth is 7 inches, let us find the number of slots

FIG. 65.

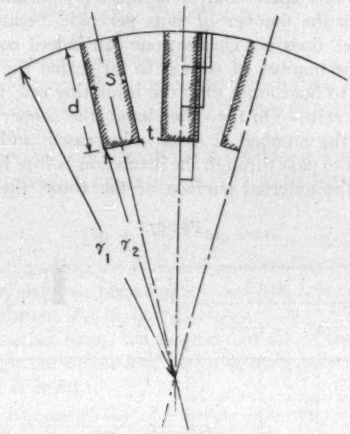
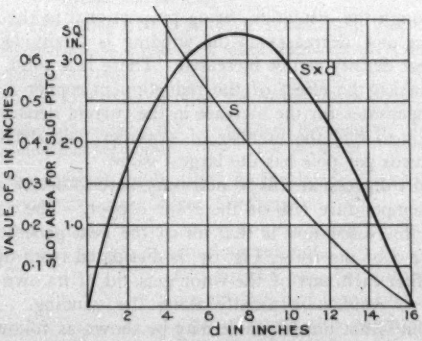



FIG. 66.

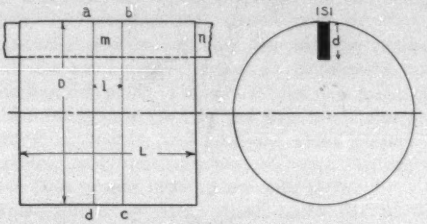



Variation of the slot area per pole with the depth of the slot.

that will give the largest excitation, the rise in temperature of the rotor copper being limited to 100° C.

The maximum slot area per pole may be obtained from Fig. 66, and this area is independent of the number of slots per pole. The part of this space that is occupied by insulating material increases with the number of slots per pole, because the thickness of the cell does not change; one can indeed conceive of the case where the number of slots is so large that the slots are not wide enough to hold more than the insulating cell, and the space for copper is zero. On the other hand, the copper loss per slot decreases as the number of slots is increased, and, as the heat generated has to pass through the insulation before it can be dissipated from the external surface of the rotor, the temperature

FIG. 67.




drop through the insulation, being proportional to the heat generated per slot, decreases as the winding is subdivided, so that the current density can be increased. There is a point, however, beyond which the effect of the reduction in copper space more than compensates for the increase in the current density, and the problem is to find the number of slots per pole for which the ampère-turns per pole has the largest value.

A short digression will be necessary here to derive a formula for the temperature rise of the rotor copper. The assumption made in this discussion is that all of the heat generated in the part *a b c d* of the rotor, Fig. 67, is dissipated from the surface $\pi Dl$, or that each part of the rotor gets rid of its own heat and there is no conduction axially along the winding. That this assumption is not unreasonable may be shown as follows:

If it is assumed that, since the copper is a good conductor of

heat and is surrounded by insulating material which is a poor conductor, the heat generated in the copper is all conducted to and dissipated from the ends, then the difference in temperature between $m$ and $n$, Fig. 67, is equal to

$$= \int_0^{L/2} (I^2 \times \frac{\rho x}{A}) \times \frac{dx}{A} \times \frac{1}{k}$$

where $I$ is the current per conductor.

$\rho$ is the resistance of a conductor 1 inch long and 1 square inch in cross-section $= 0.8 \times 10^{-6}$ ohms at normal operating temperatures.

$k$ is the thermal conductivity of a conductor 1 inch long and 1 square inch in cross-section = 11 watts per 1° C.

therefore

$$T_{mn} = \frac{\rho}{k} \frac{I^2 L^2}{A^2 8} \text{ deg. Cent.}$$

A reasonable value for $I/A$, the ampères per square inch, is 1950 (650 circular mils per ampère), and for $L$ is 60 inches, and for these conditions $T_{mn} = 125°$ C.

If, on the other hand, we assume that all of the heat is conducted through the insulation, then the heat generated per inch length of slot is equal to

$$\frac{\text{conductors per slot} \times (\text{current per conductor})^2 \times \rho_1}{\text{cross-section of conductor}}$$

$$= \frac{\text{ampère conductors per slot}}{\text{circular mils per ampère}} \times 1.0$$

since $\rho_1$, the resistance of a conductor 1 inch long and 1 circular mil in cross-section, is equal to 1 ohm approximately at normal operating temperatures.

The temperature drop through the insulation is equal to

$$\frac{\text{ampère conductors per slot}}{\text{circular mils per ampère}} \times \frac{\text{thickness of insulation}}{2 \times \text{slot depth}} \times \frac{1}{K}$$

where $K$, the thermal conductivity of insulating material in inch units, is 0.003 watt per degree Centigrade.

For a turbo-rotor with 51,000 ampère turns per pole,
10 slots per pole,
650 circular mils per ampère,
0.1 thickness of insulation in inches,
5.75 effective slot depth in inches,
the temperature drop through the insulation is 45° C.

The difference in temperature, $Tr$, between the rotor copper and the air which enters the machine is equal to $T_a + T_b + T_c$ where $T_a$ = the difference in temperature between the copper and the iron, which, as already shown, is equal to

$$\frac{\text{ampère conductors per slot}}{\text{circular mils per ampère}} \times \frac{\text{thickness of insulation}}{2 \times \text{effective slot depth}} \times \frac{1}{0.003}$$

The thickness of insulation is generally 0.1 inch.

$T_b$ = the difference in temperature between the iron and the air at the rotor surface is equal to

$$\frac{\text{watts loss per inch length of slot} \times \text{total slots}}{\pi D} \times K_r$$

where $K_r$ is the temperature rise per watt per square inch of the rotor surface and has a value of about 10 degrees Centigrade for surface velocities of the order of 20,000 feet per minute, therefore

$$T_b = \frac{\text{ampère conductors per slot}}{\text{circular mils per ampère}} \times \frac{10 \times \text{slots per pole}}{\text{pole pitch}}$$

$T_c$ = the difference in temperature between the air at the rotor surface and that entering the machine, a reasonable value for which is 15° C.

$$\text{therefore } T_r = \frac{\text{ampère conductors per pole}}{\text{circular mils per ampère}} \left[ \frac{33}{(2d) \text{ slots per pole}} + \frac{10}{\text{pole pitch}} \right] + 15$$

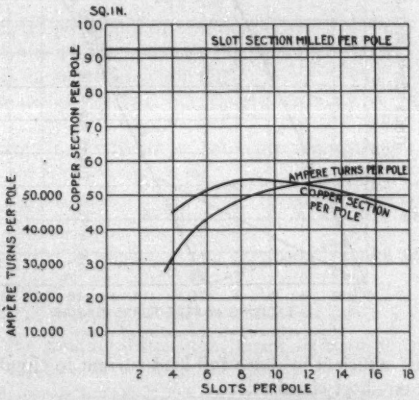
We are now in a position to find the most suitable number of slots per pole given that the rotor diameter is 51 inches, the winding belt is 0.7 times the pole pitch, or 28 inches, the slot depth is 7 inches, the stress in the rotor teeth is 14,000 pounds per square inch, and the permissible value of $T_r$ is 100° C.

| Slots per pole | Slot depth Inches | $s$, Fig. 65 Inches | $t$, Fig. 65 Inches | Depth of wedge = $f$ Inches | Copper section per slot = $(d-f-0.3)(s-0.2)\times 0.85$ Square inches |
|---|---|---|---|---|---|
| 4 | 7 | 3.34 | 1.76 | 2.6 | 10.90 |
| 6 | 7 | 2.21 | 1.17 | 1.75 | 8.46 |
| 8 | 7 | 1.66 | 0.88 | 1.3 | 6.70 |
| 10 | 7 | 1.33 | 0.70 | 1.25 | 5.22 |
| 12 | 7 | 1.11 | 0.59 | 1.25 | 4.22 |
| 16 | 7 | 0.83 | 0.44 | 1.25 | 2.92 |
| 20 | 7 | 0.66 | 0.36 | 1.25 | 2.13 |

| $\frac{10}{\text{Pole pitch}}$ | + | $\frac{33}{2d \times \text{slots per pole}}$ | | Ampère conductors per pole / Circular mils per ampère |
|---|---|---|---|---|
| 0.25 | + | 0.94 | = 1.19 | 71.5 |
| 0.25 | + | 0.52 | = 0.77 | 110 |
| 0.25 | + | 0.36 | = 0.61 | 139 |
| 0.25 | + | 0.29 | = 0.54 | 157 |
| 0.25 | + | 0.24 | = 0.49 | 173 |
| 0.25 | + | 0.18 | = 0.43 | 197 |
| 0.25 | + | 0.144 | = 0.394 | 215 |

| Ampère turns per pole, Fig. 68 | Circular mils per ampère |
|---|---|
| 31400 | 880 |
| 42000 | 760 |
| 48700 | 700 |
| 51000 | 650 |
| 52700 | 610 |
| 54000 | 550 |
| 54000 | 500 |

FIG. 68.



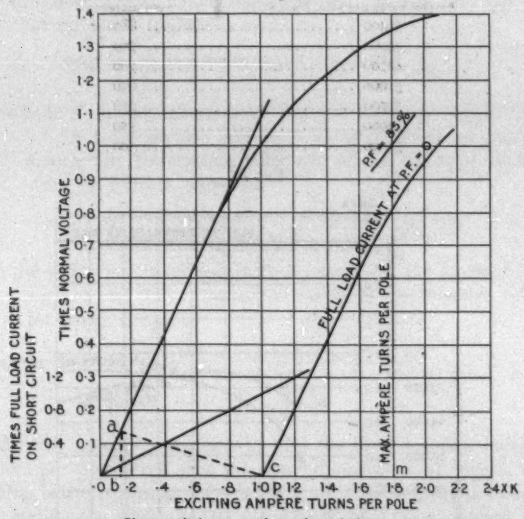

Effect of the number of rotor slots per pole on the maximum excitation.

The depth of the wedge can be decreased as the slot width is decreased, but in this particular machine it cannot be made less than 1.25 inches, because the projecting rotor coils have to be supported by a retaining ring whose thickness $y$, Fig. 58, must be sufficient to support the total weight of end-connection copper, and this weight is almost independent of the number of slots per pole.

The copper section per slot was found by assuming that the cell of slot insulation is 0.1 inch thick and that the insulation between layers occupies 15 per cent. of the available space.

*Armature Ampère Turns per Pole at Full Load.*—Fig. 69 shows typical characteristic curves of a modern alternator of large capacity. The air-gap clearance has such a value that the field excitation required to give normal voltage on no-load (namely,

FIG. 69.




Characteristic curves of a modern alternator.

*op*) is just sufficient to cause full-load current to circulate in the armature on short circuit.

The leakage reactance drop = *ab*.

= 14 per cent. of normal voltage.

The demagnetizing ampère turns per pole = *bc*.

= 0.48 (om).

= 0.48 (maximum field ampère turns per pole).

This quantity is also [23] = 0.41 (armature ampère turns per pole × 2)

therefore armature ampère turns per pole

= 0.59 (maximum ampère turns per pole).

= 0.59 × 51,000 with 10 slots per pole, Fig. 68.

= 30,000.

The corresponding value of ampère conductors per inch of stator periphery is approximately 1440.

*Generated Voltage per Conductor.*—If the rotor and the stator teeth are not highly saturated then, since the air-gap clearance is large, the flux distribution over the pole pitch is as shown in Fig. 63, and, for a winding belt of 70 per cent., the average gap density is 0.65 times the maximum value. If, then, the stator tooth density is limited to 100,000 lines per square inch, the flux per pole

$$\Phi = 100{,}000 \times \frac{t}{t+s} \times \text{pole pitch} \times L_n \times 0.65$$

where $L_n$ is the net length of iron in the core,

$t$ is the width of stator tooth tip,

$s$ is the width of stator slot.

The value of $t/s$ will not exceed 1.10 for a 13,200-volt machine.

The effective electromotive force per conductor is

$$Ec = 2.22 \times \Phi \times \text{frequency} \times 10^{-8}$$

$$= 2.22 \times (100{,}000 \times \frac{1.1}{2.1} \times \frac{\pi \times 53}{4} \times Ln \times 0.65) \times 60 \times 10^{-8}$$

$$= 1.88\ Ln \text{ for this particular machine.}$$

*The Maximum Output.*—The maximum permissible output for a machine is

$$KV.A. = k_b \times E_c \text{ ampère conductors per pole} \times \text{poles } 10^{-3}$$

where $k_b$, the winding distribution factor, is equal to 0.96 for a full-pitch, three-phase winding, therefore

$$KV.A. = 0.96 \times (1.88\ L_n) \times (30.000 \times 2) \times 4 \times 10^{-3}$$

$$= 432 \text{ per inch length of net iron.}$$

The net core length for a 30,000-kv.a. machine is therefore equal to 70 inches.

*Stator Ventilation.*—Many schemes have been suggested and used for the cooling of turbo-alternators. In modern practice

[23] "Electrical Machine Design," Gray, p. 289.

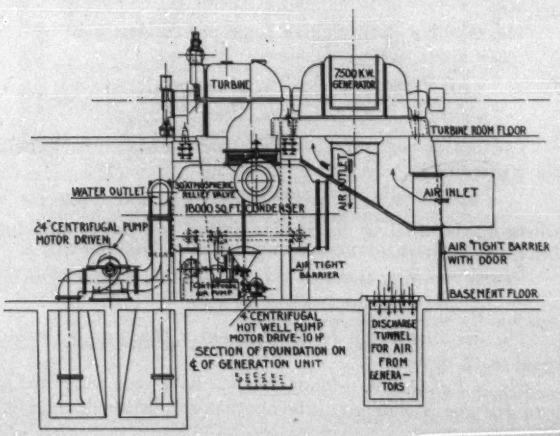
the machine is totally enclosed and air is forced through and directed on to the surfaces to be cooled. About 100 cubic feet of air is required per minute per kilowatt of loss, and this will cause the air to rise 18° C. in passing through the machine.

A turbo-alternator with a capacity of 30,000 kv.a. will have a loss on full load at 85 per cent. power factor of about 760 kilowatts, distributed approximately as follows:

| | | |
|---|---|---|
| Stator $I^2R$ | = | 37 |
| Core loss | = | 230 |
| Stray loss | = | 100 |
| | | 367 |
| Rotor $I^2R$ | = | 68 |
| Windage, friction and fan | = | 325 |
| Total | = | 760 |

This machine will therefore require about 76,000 cubic feet of air per minute, which is the contents of a room 10 feet cube emptied about 1¼ times every second. This large volume of air should not be drawn from the power-house and then discharged

FIG. 70.




Air-ducts for a turbo-alternator.

back again, because it rises 18°C. every time it passes through the machine. It is considered good practice to draw the air from outside of the building, pass it through air washers, and then through the machine, after which it is discharged outside of the

FIG. 71.

Turbine room, river station, Buffalo General Electric Company.

building by a suitable duct. Such a scheme of ventilation is partly shown in Fig. 70. The appearance of the station is then as shown in Fig. 71.

This large volume of air must be brought into close contact with the heated surfaces, and the two best-known methods of accomplishing this result are indicated in Fig. 72. In one case

the air is forced through axial ducts across the edges of the laminations, and in the other case radial ducts are provided. In the former case the duct surface is 150,000 square inches, and in the latter case 200,000 square inches are provided, so that the watts of stator loss per square inch of stator duct surface are 2.45 and 1.83 respectively; the higher value can be used with the axially ventilated machine, because the temperature drop through

FIG. 72.

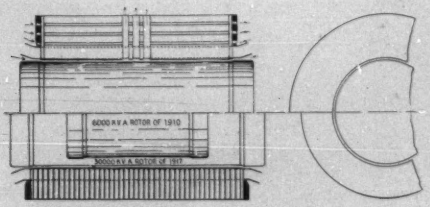
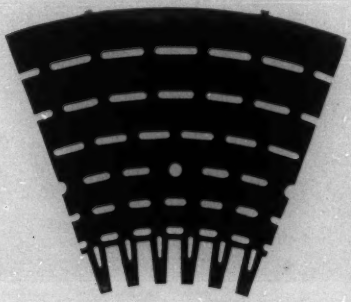



Diagram showing axial and radial ventilation of a 30,000-kv.a. turbo-alternator.

FIG. 73.



Stator punching of an axially ventilated machine.

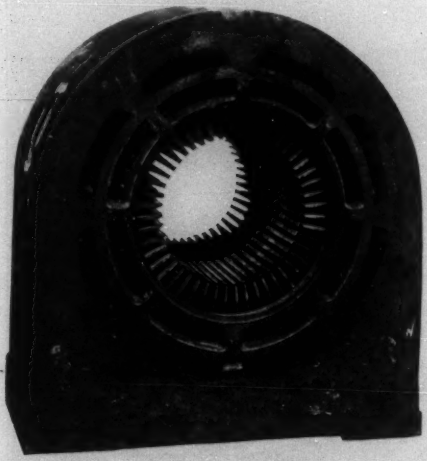
the iron part of the heat path is lower than in the machine with the radial ducts, because, in this latter case, the heat has to flow across the laminations.

*Stator Construction.*—Fig. 73 shows one of the punchings of an axially ventilated stator. The duct surface must be sufficient to limit the watts per square inch to about 2.45 and the duct

section such as to limit the air velocity to 5000 feet per minute, with an air supply of 100 cubic feet per minute per kilowatt of total loss.

Fig. 74 shows the stator assembled and ready to be wound; the air passes axially as shown in Fig. 72 and escapes through the central duct. Fig. 75 shows a machine of greater output, the volume of air being such that three central ducts are required for its escape. The stator winding, it will be noted, is

FIG. 74.



Stator of an axially ventilated turbo-alternator.

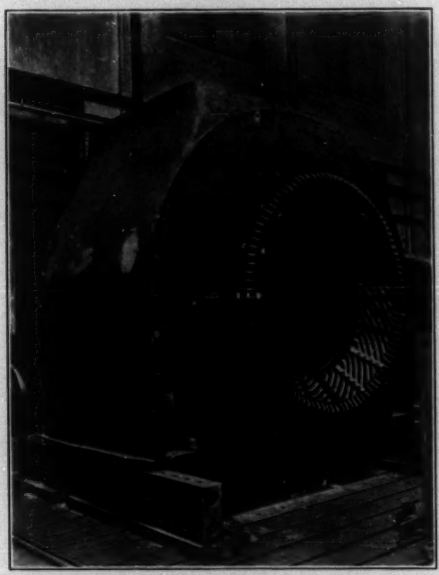
thoroughly braced on the ends so that it will be able to withstand the enormous mechanical forces that are exerted when the machine is suddenly short-circuited.[24]

The first method of cooling turbo-alternators by means of radial ducts was that covered by the Brown patents of 1901 and is shown diagrammatically in Fig. 76. This method is still used for machines up to about 1000 kv.a. capacity. Air from the

[24] "Short-circuiting of Large Electric Generators and the Resulting Forces on the Armature Windings," Walker, *Journal of the Institution of Electrical Engineers*, vol. 45, p. 295, 1910.

rotor fans is forced into the chamber *B*, whence it passes up both sides of the machine in parallel. In the case of larger machines, however, the length of path *c* becomes excessive and it becomes difficult to keep the top of the machine cool. This difficulty is overcome by introducing cool air at several points on the stator periphery, as at *A*, Fig. 77.

FIG. 75.



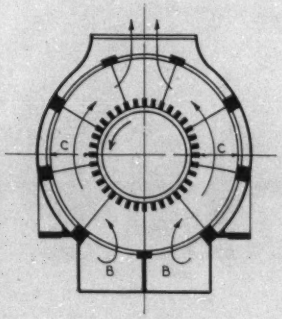
Stator of an axially ventilated turbo-alternator.

Fig. 78 shows the stator core for such a machine. Air from the rotor fans passes to the openings *A* and then through the radial vent ducts to the exits *B*. Fig. 79 shows the same machine supplied with its winding, which again is thorougly braced.

One other method of cooling used in this country makes use of the radial ducts, but these are fed from the air-gap as

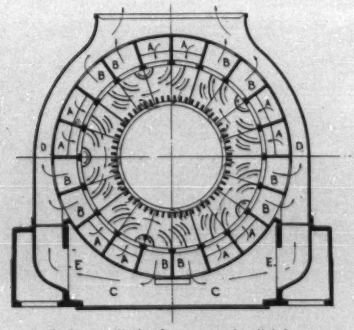
shown in Fig. 80 rather than from the outer periphery of the stator. When the ducts of a very long machine are fed in this way the velocity of the air in the gap becomes very high, and

FIG. 76.




Ventilation of small turbos.

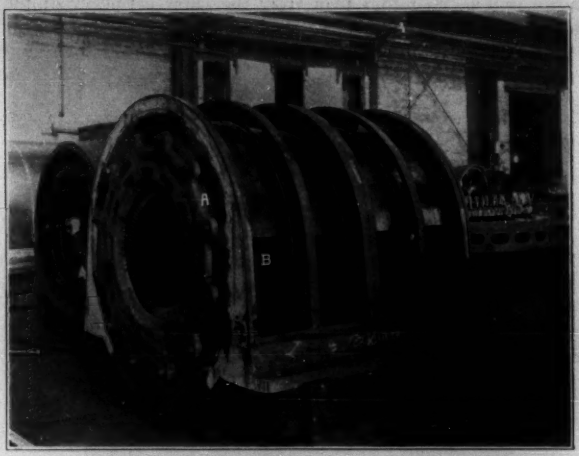
FIG. 77.




Turbo ventilation by means of radial ducts.

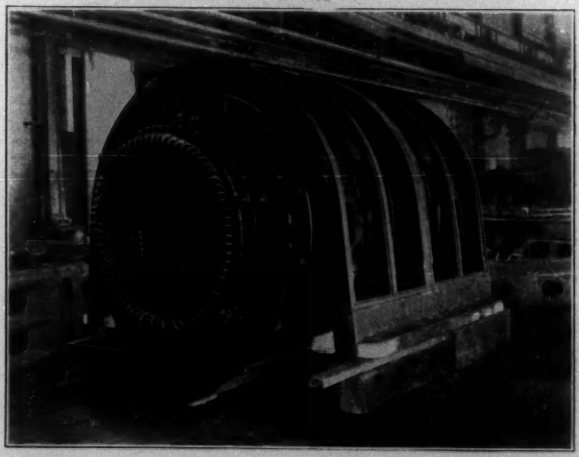
when it reaches a value of about 12,000 feet per minute it becomes desirable to feed the air-gap from the centre as well as from the ends of the machine, additional fans being added to the rotor for this purpose. Such a rotor is shown in Fig. 81.

FIG. 78.




Stator core for a machine ventilated as shown in Fig. 77.

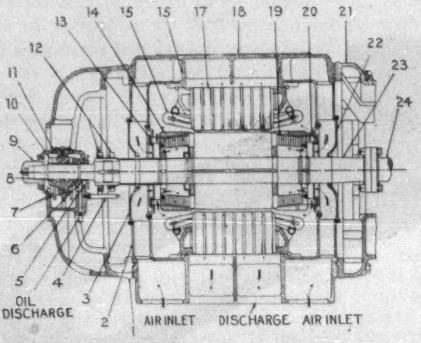
FIG. 79.



Stator for a machine ventilated as shown in Fig. 77.

In the 30,000-kv.a. machine under discussion the total loss on full load is 760 kilowatts, the volume of air required is 76,000 cubic feet per minute, the air-gap clearance is 1.75 inches, and the area of the air-path along the gap is 2 square feet, so that, if the machine is fed only from the ends, the maximum air velocity will be 19,000 feet per minute, but will have only half of this value if air is also fed into the gap from the centre of the machine. If the air is uniformly distributed to the ducts the maximum air velocity in the ducts will be less than 3000 feet per minute,

FIG. 80.




Small turbo-alternator with air-gap ventilation.

1. Outboard bearing bracket and cap. 2. Air shield. 3. Air-shield ring, outer (generator end). 4. Brush holder stud. 5. Oil deflector. 6. Oil fan. 7. Oil rings. 8. Cooling water tube. 9. End cover. 10. Lining. 11. Sight-hole plug. 12. Collector rings. 13. Air-shield rings (inner). 14. Field-retaining ring. 15. Armature coils. 16. Armature spider. 17. Armature punchings. 18. Lagging for armature spider. 19. Field coils. 20. Air fan and end flange. 21. Main bearing, cap, and connection piece. 22. Air-shield ring, outer (turbine end). 23. Shaft and revolving field. 24. Turbine half coupling and shaft.

except where the air passes through the ducts in the teeth. The velocity of the air is therefore high and the ventilation most effective in the air-gap and tooth ducts, and these are the places around which the losses are most concentrated.

All three of these solutions of the cooling problem are successful in practice. This is made certain by the insertion of thermocouples or resistance thermometers into the machine so that the temperature rise of the hottest part may be determined at any time. This temperature rise we have limited to 100° C. in the case of the rotor, and this value set a limit to the permissible

rotor excitation and therefore to the stator ampère turns per pole.

Although the number of the stator conductors has therefore been fixed, their cross-section depends on the permissible temperature rise of the stator. If the coils are insulated with varnished cloth and mica, the maximum temperature should not exceed 100° C. as measured by a thermocouple. If, on the other hand, what is called a fire-proof insulation is used, this maximum temperature may have a value of 140° C., although operating engineers are not all prepared to run machines as hot as this.

Let us then compare two stators, one with a rise of tem-

FIG. 81.

35,000-kw., 1200-r.p.m. Curtis steam turbine. The inner fans feed the air-gap from the ends and the outer fans feed it from the centre of the core.

perature of 75° C. and the other with a temperature rise of 100° C., which are reasonable figures if the air is passed through an air-washer and enters the machine with a temperature of 25° C.

In the high-temperature stator the current density is 15 per cent. greater, the slot is 15 per cent. shallower, and the temperature gradient through the insulation is 32 per cent. greater than in the low-temperature stator. The flux density in the core is increased 10 per cent., the duct surface is decreased 10 per cent., the core loss is increased 20 per cent., and the temperature drop at the duct surface is increased 32 per cent. The difference

between the two stators is therefore that the low-temperature machine has 15 per cent. more stator copper, 10 per cent. more stator iron, smaller loss, and higher efficiency, while the rotor is the same for each machine.

The effect of desired voltage regulation on the output was discussed in the previous article. The maximum excitation, *om*, Fig. 69, is fixed in the case of a turbo-alternator, and the regulation can be improved only by a reduction in the reactance drop *ac* and in the armature reaction *bc*, and this can be accomplished only by a reduction in the armature ampère turns per pole and a corresponding reduction in the output. Fig. 72 shows the dimensions of a 6000-kv.a., 1800-r.p.m. machine with a rotor built for a maximum temperature rise of 100° C. with full-load current at zero power factor and for a regulation of 25 per cent. at 85 per cent. power factor.

Outputs greater than those at present obtained from a given frame are possible, provided the regulation is still further sacrificed and the temperature rise further increased.

(*To be continued.*)

---

**Car Nosing.** S. A. BULLOCK. (*Electric Railway Journal*, vol. 50, No. 4, p. 149, July 28, 1917.)—Car nosing, which is horizontal oscillation of the car body about instantaneous axes, occurs on tangent track and is usually negligible on curves. In passenger service a slight amount of nosing is preferable to the rigid transverse shock of non-swinging bolsters, but when these oscillations become excessive, nosing becomes a question of serious moment. The initial cause of nosing is poor track; that is, low joints and irregular gauge, which force the wheels to slide horizontally, producing a horizontal force at the wheel. This horizontal blow is transmitted through the axle to the various members of the truck, and finally to the car body.

Theory and practice both prove that nosing is reduced with long distances from centre to centre of king-pins and with heavy passenger loads. Nosing can be minimized by the following expedients: (1) Improvement of track conditions by levelling the low joints, keeping normal track gauge, and using proper weight of rail. (2) Reducing lateral play in the transverse moving parts by renewal of worn pieces, and breaking up synchronism of the movements by variable damping of the transverse motions in the front and rear trucks. (3) Reducing the overhang of the car body by lengthening the distance, centre to centre, of king-pins and reducing the overhang of the motors by placing the motors inside of the wheels.

**A Cuprous Oxide Photo-chemical Cell.** T. W. CASE. (*Proceedings of the American Electrochemical Society*, May 2–5, 1917.)—A large amount of work has been done on cells that produce an electromotive force on exposure to light. Becquerel, the pioneer in this field, and later Minchin and others, found that a large number of combinations could be developed that would produce a current under the influence of light. They worked out in detail a number of light-active cells consisting of silver salts upon some metal plate, and in these they observed certain peculiar reversals of current which they were unable to explain. These difficulties were later studied by Wildermann, who worked out equations applying to the action of photo-chemical cells, starting with the fundamental conception "that the chemical potential of a substance in light and dark is different, becoming greater in light."

In nearly all these photo-chemical cells the output was very small (amperes in units of $10^{-9}$ and volts in units of $10^{-6}$). This, together with the unsatisfactory action, the ultimate consumption of the elements, and the difficulty of accurate observation of the actual processes taking place due to complicated side reactions, has tended to check research in this field. Since, however, the more photo-chemical reactions that are known, with their different modes of action, the more chance we have to understand the phenomena, the author has undertaken a search for new substances and combinations which show a voltage effect in light.

A systematic search was begun in the first instance with copper salts. A large number of electrolytes were found which would deposit a light-active coating upon copper, probably due to the formation of a copper oxide or halide salt upon the electrode. A copper formate electrolyte, containing free formic acid, using highly polished copper electrodes, was studied closely. If one plate be illuminated and the other kept dark, a current is produced, the illuminated plate being anode, and developing an electromotive force up to 0.11 volt. The current finally drops to zero; but if the cell is rotated, illuminating the previously dark plate, the electromotive force reappears. On continued rotation the electromotive force reaches a maximum value. Below a critical light intensity the cell gives very little response.

## NOTES FROM THE U. S. BUREAU OF STANDARDS.*

### THE LATENT HEAT OF VAPORIZATION OF AMMONIA.

By Nathan S. Osborne and Milton S. Van Dusen.

[ABSTRACT.]

THE latent heat of vaporization of liquid ammonia has been determined throughout the temperature interval $-42°$ to $+52°$ C. by direct measurements, using a calorimeter specially designed for the particular problem. This instrument is of the aneroid or unstirred type, the ammonia being the only liquid in the calorimeter. Heat developed and measured electrically in a coil is transmitted by conduction and convection to the ammonia, and is expended in the evaporation of a determined amount which is withdrawn as superheated vapor. Accessory data from other sources are required only in the computation of small correction terms. The results are expressed by an empirical equation and a table of values given for every degree from $-45°$ C. to $+55°$ C. By combining the data for the heat of vaporization with the data for specific heat of the saturated liquid from a previous investigation, the specific heat of saturated ammonia vapor is obtained and a table of values of this quantity is given in an appendix.

### MAGNESIA IN PORTLAND CEMENT.

[ABSTRACT.]

IN order to determine what new constituents are produced in Portland cement, when the magnesia content is raised considerably above that permitted by present standard specifications, and in order further to determine what effect these new constituents would have upon the physical properties of the material, a number of cements were burned in the rotary kiln of the Bureau. In these the magnesia content varied from 1.7 per cent. to 25.5 per cent. In all 18 different cements were produced in two series of nine burnings each. In both series the compositions were those of normal cement, excepting the magnesia content only.

* Communicated by the Director.

But in one case the silica content was somewhat higher and the alumina content somewhat lower than in the other case.

As raw materials, clay, kaolin, feldspar, limestone, and dolomite were used. In the one series, the cement of lowest magnesia content was made of a raw mix containing limestone, clay, and a small amount of feldspar, the latter being added to increase the silica-alumina ratio over that obtainable with clay and limestone alone. The magnesia in the other burns of this series was increased by replacing the limestone with dolomite. In the second series the raw mixes were composed of clay, limestone, and a small amount of kaolin, the latter being used to decrease the silica-alumina ratio over that obtainable with the clay alone. In this series, also, increasing amounts of limestone were replaced with dolomite, until dolomite alone was used.

The deportment of the high magnesia cements in the kiln was very characteristic. There was a reduction of the clinkering temperature with increasing magnesia content, though to produce satisfactory clinker this was not as marked as expected. But to prevent the dusting of the clinker of the higher magnesia content cements it was necessary to overburn to a very hard, vitreous mass. This mass in the kiln was about of the consistency of putty, and as a result there was a decided tendency to form "logs" and "rings." The clinker was also of a reddish-brown color, which gave a decided brownish tinge to the ground cement.

A microscopical examination of the clinker showed that increasing amounts of magnesia produced an increasing size of crystals and granularity. When the magnesia exceeded 8 per cent., a constituent (monticellite) not present in normal cement was noted. When the magnesia was still further increased to an amount exceeding 10 per cent., another constituent—spinel—not present in normal cement, was also noted. It was also noted that those constituents—tricalcium silicate and tricalcium aluminate—which produced quick setting and early strength, were not materially decreased by the appearance of the new constituents; whereas, the orthosilicate of lime, which produces the later hardening and modifies the early setting of the other constituents, was decidedly decreased in amounts.

The effect of the higher magnesia, when not exceeding 8 per cent., was not very noticeable in any of the physical properties. Higher amounts produced a quick initial set and an apparent slow

final set. The strength both in tension and compression of neat and mortar specimens, and of concrete specimens in compression, when 8 per cent. was not exceeded, was very comparable with the strengths produced by cements of normal magnesia content. Above these amounts the early strengths were less, but showed a consistent gain with age.

Specimens are still available for examination and breaking at later periods than those reported in this paper.

---

## THE EFFECT OF HEAT ON CELLULOID AND SIMILAR MATERIALS.

By H. N. Stokes and H. C. P. Weber.

[ABSTRACT.]

WHEN thoroughly cleansed cotton is immersed in a mixture of sulphuric and nitric acids, more or less of the latter acid combines with the cotton (cellulose), the amount depending upon the strength of the acid and on how long it is allowed to act. The most highly nitrated product is gun-cotton, the less nitrated being commonly known as pyroxylin, soluble cotton, etc. Pyroxylin, when dissolved in a suitable liquid, forms collodion. Mixed with camphor or similar substances, it yields the product popularly known as "celluloid," though legally this word should be applied only to material manufactured by one American company. The term pyroxylin plastics is of wider applicability.

Gun-cotton would be worthless if it did not break down or decompose with explosive violence, and the question naturally arises, To what degree do the closely related pyroxylin plastics share this instability? It is well known that they are readily ignited and burn rapidly. Evidence as to their explosiveness is contradictory, and instances of supposed spontaneous ignition have been published from time to time. The work described in this paper was done in the attempt to settle some of the questions involved.

Weighed samples, wrapped in tissue paper, were kept at various temperatures and afterwards reweighed and examined. It was found that even at the boiling-point of water there was considerable loss in weight, and some of the samples swelled up and formed brittle, spongy masses, while the wrappings were partially charred. When other samples, unwrapped, were heated to 135° C.

(275° F.), many of them ignited or exploded in less than two hours. At the same time, considerable volumes of combustible and poisonous gases were given off.

Still other heating experiments showed that samples of celluloid were more liable to ignite or explode—in other words, were less stable—than parlor and safety matches, black gunpowder, and two grades of smokeless powder.

Thin strips of celluloid burned many times as rapidly as paper or strips of wood of the same width and thickness. Sticks of wood 13 millimetres (½ inch) square would not continue to burn when lighted, but celluloid sticks of the same size burned almost as rapidly as the thin strips.

Although the results of the experiments show that celluloid is a highly inflammable and even explosive substance, the Bureau of Standards disclaims any wish or intention to discourage the use of this material. It can only inform the public of the necessity for reasonable carefulness in using and handling it.

## TESTS OF LARGE BRIDGE COLUMNS.[1]

**By J. H. Griffith and J. G. Bragg.**

[ABSTRACT.]

THE investigation gives a comparative analysis of the experimental data found upon 18 large bridge columns when they were tested in the 10,000,000-pound testing machine. The action of each column as a whole was studied in a range of loadings taken to destruction of the members. Numerous observations were made to determine the behavior of lattice bars, pin plates, diaphragms, etc. The causes and effects of initial strain from riveting and fabrication were discussed.

## GAS MANTLE LIGHTING CONDITIONS IN TEN LARGE CITIES IN THE UNITED STATES.[2]

**By R. S. McBride and C. E. Reinicker.**

[ABSTRACT.]

FROM a careful inspection of about 4500 gas mantle lamps in service in ten cities a summary of the condition of mantles, glassware, pilot light, and other particulars was made in order

[1] Technologic Paper No. 101.
[2] Technologic Paper No. 99.

to determine to what extent the customer benefited through periodic maintenance service.

By these observations it is found that a lamp not on regular maintenance is likely to be defective 5½ times as frequently as a lamp which is regularly maintained. Also, it is shown that, on the average, one in three of the lamps on regular maintenance was not in good condition, whereas the defects noticed in the lamps not so maintained average more than one for every lamp.

The principal defects in maintenance systems were also investigated, and one satisfactory system of estimating the expenses for maintenance work, together with a set of unit costs, is presented, based upon the analysis of the operation of ten gas companies. A suggested table of costs for each type of unit is given.

---

## PAINT AND VARNISH.[3]

[ABSTRACT.]

THIS publication is intended to give, without unnecessary detail, information which should be of value to those interested in the use of paint and varnish. After a general discussion and classification of paints and varnishes and an explanation of the process of "drying," the raw materials, including oils, driers, thinners, resins, and pigments that enter into the composition of paint or varnish, are individually described. The methods of manufacture and of testing varnishes are presented, ready-mixed or prepared paints are discussed, and somewhat detailed instructions on mixing paints and stains, on color blending, and on the application of paint and varnish to various surfaces are given. Specifications in common use for many of the materials treated and a glossary of painters' terms also appear.

---

## RULES AND REGULATIONS PROMULGATED UNDER AUTHORITY OF THE FEDERAL STANDARD BARREL LAW.[4]

[ABSTRACT.]

SECTION 3 of the Federal Standard Barrel Law (38 Stat., ch. 158, p. 1186: 63d Cong.) reads in part as follows:

"SEC. 3. That reasonable variations shall be permitted and tolerances shall be established by rules and regulations made

[3] Circular No. 69.
[4] Circular No. 71.

by the Director of the Bureau of Standards and approved by the Secretary of Commerce. . . ."

This circular contains the rules and regulations which are authorized by quoted part of the above law. The text of the law is included as an appendix to the publication.

---

### MATERIALS FOR THE HOUSEHOLD.[5]

[ABSTRACT.]

DESCRIBES the more common materials used by the household, comprising paint materials, cement, clay products, lime, plasters, and stucco, wood, metals, bituminous roofing, inks and dyes, adhesives, paper, textiles, rubber, leather, cleansers and preservatives, fuels, illuminants, lubricants and a concluding chapter on quantity in the purchasing of materials. Each title is treated under the general heads of composition and definition, sources, properties, uses, tests, preservation, hints as to selection and use, and references.

---

### COMBINED TABLE OF SIZES IN THE PRINCIPAL WIRE GAUGES.[6]

[ABSTRACT.]

A TABLE combining in one series the sizes in the American (B. and S.), Steel, Birmingham (Stubbs's), British Standard, and Metric Wire Gauges, arranged in order of diameters of wires. It gives the diameters of all the gauge numbers in these five systems in mils, inches, and millimetres, also the cross-sections in square mils, circular mils, square inches, and square millimetres. The table is specially useful to manufacturers who wish to determine the nearest equivalent in American or British gauge sizes of wires specified in millimetres or square millimetres, or *vice versa*.

---

### THE DETERMINATION OF ABSOLUTE VISCOSITY BY SHORT-TUBE VISCOSIMETERS.[7]

**By Winslow H. Herschel.**

[ABSTRACT.]

THE Engler and the Saybolt Universal viscosimeters, which are the instruments usually employed in the oil trade, have such short outlet tubes that the equation for the flow through long

[5] Circular No. 68.
[6] Circular No. 67.
[7] Technologic Paper No. 100.

capillary tubes is not applicable without correction factors. The literature has been carefully reviewed and further experimental work has been done. The conclusion is reached that water is not a suitable liquid for use in finding the relation between viscosity and time of discharge for short-tube viscosimeters, and that Ubbelohde's equation, and all others based upon it, are seriously in error.

---

**Speed Control and Stopping Devices.** Anon. (Safety Standards of the Industrial Board, Pennsylvania Department of Labor and Industry, Electric Code, vol. 1, No. 21, p. 59.)—The importance of automatic speed-limiting devices for certain types of prime movers is becoming better realized. More cases of rotating parts failing by overspeed occur than of boiler explosions, which are so seriously regarded. With steam turbines and belted water turbines such limiting devices are particularly needed. Even reciprocating engines are frequently fitted with extra valves and independent speed-limiting mechanisms. Water turbines in many cases have deflecting nozzles or vanes, usually operated by the governor, which serve to prevent overspeed. Generators driven by prime movers carry a load which may become nearly zero by the opening of automatic cut-outs. The speed-limit device may therefore need to be very quick acting, and yet, in cutting off the steam or water supply from the engine or turbine, must not cause any damage to the feeder piping.

Separately excited, direct-current motors are particularly liable to "run away," since their field excitation current may be greatly reduced, while the armature current still is maintained. To a less degree series motors, motor generators operating in parallel, or feeding storage batteries, and rotary converters are also subject to "runaways." Where directly connected to mechanical load, dangerous overspeed is not likely to occur, but where belt connected or having only a generator load, which may be readily lost by the opening or automatic cut-outs, the danger of overspeeding is considerable. Centrifugal devices which at high speeds actuate trip devices for opening the source of energy supply are most often utilized as means of protection against such a contingency.

With direct-current motors having speed adjustment through field control, dangerously weak fields must be avoided, since excessive speed may result from this cause, especially when the load is belt connected to the motor or consists of generators. Release coils, whether placed on starting rheostats or otherwise, in which the field circuit passes through the coil, are among useful means for preventing the dangerous weakening of fields during operation. In some cases centrifugal speed-limiting devices are installed.

Provision of more than one manual control device is often desirable for stopping prime movers or motors, since in emergencies this may save valuable time, especially where the equipment is of considerable extent and much distance might have to be traversed in order to reach a single point of control. Through the use of relay control circuits a single valve or main switch can readily be operated from several points.

The relative importance of electrical circuits controlling stopping devices, together with the natural frailty of the comparatively small conductors employed, makes the use of conduit or other mechanical protection essential to assure reliability.

The use of closed circuits assures that any chance open circuit will immediately give evidence of its existence through lamps or bells connected in the circuit. With open circuits a break in the circuit may not be discovered until in an emergency the control may be found inoperative. Where, as with motor-operated switches or valves, the control circuits must be normally open, it will be necessary to depend on the mechanical protection of the circuit for its maintenance in operative condition.

**Coke from Peat.** ANON. (*La Chronique Industrielle*, vol. 40, No. 295, p. 7, June 20, 1917.)—The Peat, Coal, and Oil Syndicate of Doncaster, Yorkshire, is developing a new method for treating a special variety of dry black peat and converting it into a hard foundry coke, the by-products being tar and tarry liquids from which automobile oils can be obtained by distillation. It is not claimed that all varieties of peat can be profitably used, but it is said that hundreds of acres containing millions of tons of peat can be commercially utilized by this process.

The black layer at the bottom of the bog is most suitable for the manufacture of coke. This material is freed of its excess of water and subjected to a carbonizing process by means of which by-products are recovered, the residue being a soft and friable coke. Notwithstanding that peat coke has lower sulphur content than any other combustible, up to this time its insufficient hardness has been an obstacle to its application in blast-furnace operation. This fault, it is claimed, is now overcome, and a hard, strong, and pure coke is now obtained. A German chemist has proved by analysis that 1000 tons of air-dried peat will produce 400 tons of coke, 40 tons of tar, and 400 tons of tarry liquids. The tar can be further distilled to yield 18 tons of crude oil, two tons of creosote, two tons of pitch, and eight tons of paraffin. The tarry liquids will yield four tons of sulphate of ammonium, six tons of acetate of lime, and two tons methyl alcohol. It is estimated that there will be a profit of 90 c. (centimes?) on every ton of peat so treated.

## NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

### THE PRODUCTION OF SEPIA TONES BY DIRECT DEVELOPMENT.[1]

By Adolph Nietz and Kenneth Huse.

[ABSTRACT.]

It is well known that slow developing-out photographic papers will give warm tones if overexposed and developed with a strongly restrained developer. Observations recorded in this paper were made in order to find the best conditions for producing sepia tones by this method.

The process is attended by uncertainties and is not by any means easy, but with great care in manipulation excellent sepia prints can be obtained with some subjects. The tone depends only upon the time of development, and with this time fixed good reproduction of tone can be secured, the exposure then being adjusted to get the necessary depth of print. For obtaining good sepia tones corresponding to the sepia water-color manufactured by Winsor & Newton, and free from the objectionable smokiness in the shadows, this process is particularly suitable. Since in development the print starts as a red-brown and passes through brown, sepia-olive, sepia, and olive, any of these tones can be obtained under given conditions.

Artura chloride is the only paper with which the writers could obtain satisfactory results, and it is to be understood that all subsequent statements imply the use of this material.

The most satisfactory developing agent was found to be chlorhydroquinone. Elon, hydroquinone, and other substituted hydroquinones were investigated, but chlorhydroquinone has the necessary properties for use as a restrained developer—proper sensitiveness to restraining agents, freedom from fog and staining, and stability.

* Communicated by the Director.

[1] Communication No. 53 from the Research Laboratory of the Eastman Kodak Company, published in *British Journal of Photography* and *American Photography*.

The best working formula was found to be

| | |
|---|---|
| Chlorhydroquinone | 5 gm. |
| Sodium sulphite | 30 gm. |
| Sodium carbonate | 16 gm. |
| Potassium bromide | 6 gm. |
| Potassium metabisulphite | 6 gm. |
| Water | to 1000 c.c. |

With this as a basis, a systematic series of experiments on the effect of each constituent was carried out. The principal fact brought out was the necessity of securing a proper balance between the concentration of potassium bromide and that of the potassium metabisulphite.

That the tone is dependent only on the time of development was indicated by the manner in which the print changed continuously in color while in the developer, as already stated. Any of the colors can be obtained by stopping development at the proper time. As the prints change color in the fixing bath and again on drying, judgment of tone should be based entirely on the appearance of the finished print. By developing test-strips for different known lengths of time, the correct time of development for any desired tone is determined.

The exposure being excessive (about 75 to 100 times normal), the use of nitrogen-filled tungsten lamps or other powerful light sources is recommended. When correctly exposed, the image is slightly printed out.

Since the process tends to shorten the scale of the paper by increasing the contrast, the range of negatives suitable is more limited than for ordinary reproduction. With soft portrait negatives of a certain type, good prints may be obtained using such tones as olive-sepia or decided olive, but another class of work for which this process is perhaps best adapted is the reproduction of paintings and etchings. A rich etching-sepia is readily secured in the latter case.

The image is not due to any oxidation product, but consists of silver, and the color depends on the state of division. For this reason prints made by this method are permanent.

Specific directions for working the process are given in the full paper to which reference has been made.

## NOTES FROM THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.*

### THE SHAPES OF GROUP MOLECULES FORMING THE SURFACES OF LIQUIDS.[1]

By Irving Langmuir.

THIS paper outlines the author's theory of the shapes of group molecules, particularly of organic compounds, and gives the principles and results of his measurements of cross-sections and lengths of molecules.

In accordance with the theory of adsorption and surface tension earlier stated,[2] as well as considerable experimental evidence, adsorbed films on plane surfaces of solids or liquids should be, in general, one atom or group molecule thick.

When an oil is placed upon water the COO groups combine by their secondary valences with the surface of the water, while the hydrocarbon chains remain combined with each other. Spreading continues until all available COO groups have come in contact with the water, and then ceases. The hydrocarbon chains then extend above the water away from the COO groups on the surface, and their dimensions may be measured from the weight of oil, area which it covers, density, and molecular weight. The values for fifteen different organic compounds are given. The cross-sections vary from $21 \times 10^{-16}$ sq. cm. to $280 \times 10^{-16}$ sq. cm., and the lengths from $5.7 \times 10^{-8}$ to $44.0 \times 10^{-8}$ cm.

The bearing of the data upon the position of various radicals is discussed.

The theory is supported both by Gibbs's method of calculating the material adsorbed in the surface of a liquid from the change of surface tension, and still more conclusively by Szyszkowski's measurement of surface tension for certain organic acids, which last indicate that in each case the same number of molecules are adsorbed in the surface layer.

* Communicated by the Director.

[1] *Proceedings of the National Academy of Sciences*, 3, 251–257 (1917).

[2] Langmuir, *J. Amer. Chem. Soc.*, 38, 2221–2295 (1916).

The article is already so condensed that anything in the form of an abstract omits material of significance. A more extended treatment will probably be soon published in the *Journal of the American Chemical Society*.

## TUNGSTEN ELECTRODE LOSS IN THE HYDROGEN ARC.[3]

**By G. M. J. Mackay and C. V. Ferguson.**

A 2-MM. arc was run for 1.265 minutes in a 12-cm. spherical bulb containing 300 mm. pressure of hydrogen. The characteristics were:

| | |
|---|---|
| Initial | 201 volts, 1.40 ampères |
| Final | 245 volts, 1.40 ampères |

The temperature of the faces of the electrodes was 3112° K. for the cathode and 3151° K. for the anode. The cathode gained 75 per cent. of the loss in weight of the anode, and the rate of loss of the latter was not appreciably greater than would occur from the normal evaporation of the metal due to its temperature alone. The metal leaving the anode becomes positively charged and migrates to the cathode. The number of atoms carried for each unit charge is about $10^{-4}$.

## THE CRYSTAL STRUCTURE OF ALUMINUM AND SILICON.[4]

**By Albert W. Hull.**

THE crystal structure of aluminum and silicon has been determined by passing a narrow beam of monochromatic X-rays from a Coolidge tube with molybdenum target through a continuously rotated tube of the finely powdered metal and photographing the diffraction images of the slit. The positions and intensities of the lines in the photograph are compared with the theoretical values for different possible arrangements of atoms until an arrangement is found which represents completely the observed lines.

A tabulation of the lines observed and the corresponding spacing, calculated from the angle of the line and the wave-length, the theoretical spacing of the assumed lattice, and the index of the plane producing each line, is given.

Aluminum, which has usually been considered to belong to the

[3] *Physical Review*, 9, 573, 574 (1917).
[4] *Ibid.*, 9, 564–566 (1917).

isometric system, is shown to be tetragonal. The unit of structure is a centred rectangular prism, with a square base of 2.85 A., side and height 4.05 A., with an atom at each corner and one in the centre of the prism. The atoms per unit parallelopiped are 2.

Silicon has a lattice identical with that of the diamond, two face-centred lattices intermeshed, the one being displaced with reference to the other along a cube diagonal a distance of one-fourth the length of the diagonal. The side of the cube is 5.43 A., compared with 3.56 A. for diamond, and the distance between nearest adjacent atoms is 2.35 A., compared with 1.54 A. for diamond. The number of atoms per unit cube is 8.

## THE EFFECT OF X-RAYS ON THE LENGTH OF LIFE OF TRIBOLIUM CONFUSUM.[5]

**By Wheeler P. Davey.**

THE action of X-rays upon the flour weevil (*Tribolium confusum*) has been studied with extreme accuracy of measurement, and control of other factors which might impair the accuracy of the observations. Probability curves have been plotted from the data in order to determine the idiosyncrasy of the organism.

X-rays above a certain threshold dose cause premature death after a latent interval whose duration is given by $Y = A - B \log X$ where $Y$ is the length of the latent interval and $X$ is the X-ray dose in terms of electrical input of tube, anti-cathode material, etc. The dose was varied by length of exposure, voltage current and distance being held constant.

The threshold dose with a standard Coolidge tube operating on sine-wave voltage without filters is 500 milliampère-minutes at 25 cm. distance at 50 kilovolts.

The influence of wave-length and of sterilizing effect of doses below the lethal dose is being studied.

## THE CRYSTAL STRUCTURE OF IRON.[6]

**By A. W. Hull.**

THE analysis was made first on a single crystal, 6 mm. square and 2 mm. thick, of steel containing about 3.5 per cent. of Si and practically no carbon, and then on pure iron powder. The K lines

[5] *Physical Review*, 9, 557, 558 (1917).
[6] *Ibid.*, 9, 84-87 (1917).

appeared very clearly at 110,000 volts, and their distance from the centre of the beam could be measured. Comparison with an assumed structure of atoms arranged in a centred cubic lattice, with the scattering electrons in each atom concentrated at its centre, failed to account for all the lines. Displacement of all the electrons from the centre along the cube diagonals in four groups of 2, 8, 8, 8, at distances $^1/_{32}$, $^1/_{16}$, $\frac{1}{8}$, and $\frac{1}{4}$ respectively of the distance to the nearest atom, makes it possible to account for all the observed facts within the limit of the experimental error.

Although but a rough approximation, the excellent agreement indicates that this is a step in the right direction. Iron is given its correct valence thereby.

---

## THE EFFECT OF X-RAYS ON THE LENGTH OF LIFE OF TRIBOLIUM CONFUSUM.[1]

**By Wheeler P. Davey.**

THIS is a detailed account of the work briefly described in the *Physical Review*, 9, 557, 558 (1917). A short review of the literature of the effects of X-rays on various forms of animal life is given.

The characteristics of *Tribolium confusum*, and the methods of manipulation employed to eliminate sources of error and the individual idiosyncrasy of the beetles are described in full.

A dose of 15,000 $\frac{\text{M.A.M.}}{25^2}$ at 50 kilovolts killed all beetles during administration. Doses less than 500 $\frac{\text{M.A.M.}}{25^2}$ at 50 kilovolts were not fatal to all the beetles.

---

## THE PLIOTRON OSCILLATOR FOR THE PRODUCTION OF LARGE CURRENTS OR HIGH POTENTIAL AT HIGH FREQUENCIES.[2]

**By William C. White.**

THE use of a pliotron of the same type of design as that recently described[3] as a sort of converter to supply alternating-current energy from a direct-current source is described.

---

[1] *General Electric Review*, 20, 174–182 (1917).
[2] *Ibid.*, 20, 635–637 (1917).
[3] *Ibid.*, 19, 771 (1917)

The principles and connections of arrangements of pliotrons for (1) the production of relatively large current and (2) for the production of relatively high voltage, both involving amounts of energy of the order of 150 volts or less, are given.

A diagram is shown (1) to produce currents of from 10 to 25 ampères from one tube at frequencies between 100,000 and 1,000,000 cycles, for such uses as calibrating a hot-wire ammeter by direct comparison with a standard.

The nearly reverse conditions for (2) are also described and shown. Both arrangements can be operated from a direct-current source betwen 200 and 750 volts, and at 100,000 cycles a voltage of 120,000 may be obtained from one pliotron tube operating from a 500-volt, direct-current source. For higher voltages tubes may be operated in parallel.

---

## RÖNTGEN RAYS FROM SOURCES OTHER THAN THE FOCAL SPOT IN TUBES OF THE PURE ELECTRON DISCHARGE TYPE.[10]

**By W. D. Coolidge and C. N. Moore.**

THIS paper is a detailed study by means of the pinhole camera of the amount and distribution in the Coolidge X-ray tube of radiations that might tend to blur the röntgenogram. Illustrations show the relative intensity of the X-rays given off from different parts of the target, the effect of size of bulb and of increase of voltage, and the efficacy of various hooding and other devices for intercepting such radiations. Test pictures made under comparable conditions, with and without the use of such devices, are given.

The conclusion reached is that with the present technique it is not possible for even skilled röntgenologists to distinguish between the pictures taken without and those taken with such shielding devices. While the presence of X-rays emanating from other parts than the focal spot can be demonstrated, it is not of practical significance at this time.

---

[10] *General Electric Review*, 20, 272–281 (1917).

**Water Powers Conserve Labor.** H. L. COOPER. (*Electrical World*, vol. 69, No. 25, p. 1200, June 23, 1917.)—Secretary Lane has recently stated that there is in the United States 35,000,000 water horsepower undeveloped. The attacks on water-power engineers and developers began in 1903, and since that time the aggregate falling off in water-power development amounts to more than 5,000,000 horsepower. In other words, if water-power development had been encouraged during this period and continued at the normal rate of development prior to 1903, we should have an additional 5,000,000 horsepower at work to-day, and the public would be fixing the rates to be paid for this great additional amount of energy. The consumers would be enjoying a saving of at least $50,000,000 annually in their power bills, and 100,000 laborers now engaged in following coal from the vein to the ash pile would be free for other more important work. Moreover, the development of this 5,000,000 horsepower would have been of great benefit to our farmers, because of the cheap fertilizer it would have produced. Besides this, about $274,000,000 worth of railroad equipment now hauling equivalent coal would be available for other most important needs.

Power in all its forms in the United States has been steadily going downward in cost for many years, yet in spite of this the average selling price of hydro-electric power is about $10 per horsepower less than the price of the same unit by steam. The crops in France, in England, in Germany, and in the United States are all suffering to-day from want of fertilizers. Volumes have been written showing that fertilizers, intelligently used, would about double the present farm production of the United States. The primary basic need of fertilizers is nitrogen; and this can be most economically produced by the arc process from the air. Ours is the only large country in the world where fertilizers by this process are not in successful use.

# THE FRANKLIN INSTITUTE.

## LIBRARY NOTES.

### PURCHASES.

ABEGG, R.—The Electrolytic Dissociation Theory. 1907.
American Electrochemical Society.—Transactions, vol. 30. 1917.
COLVIN, F. H.—Practical Die-making. 1916.
FAY, H.—Microscopic Examination of Steel. 1917.
FURMAN, F. DeR.—Elementary Cams. 1916.
Illuminating Engineering Society.—Illuminating Engineering Practice. Lectures, 1916.
International Catalogue of Scientific Literature.—Chemistry, D., No. 13. 1916.
JOLY, J.—Synchronous Signalling in Navigation. 1916.
KEHL, R. J.—Oxy-acetylene Welding Practice. 1917.
KENNEDY, R.—Flying Machines, Practice and Design. 1909.
KENT, R. T.—Power Transmission by Leather Belting. 1916.
Poor's Manual of Public Utilities. 1917.
SHAILON, F. E.—Tool and Die Design for Beginners. 1917.
TALBOT, F. A.—Aeroplanes and Dirigibles in War. 1915.
TILDEN, SIR W. A.—Chemical Discovery and Invention in the Twentieth Century. 1916.
WEEKS, L. H.—History of Paper Manufacturing in the United States, 1690–1916.

### GIFTS.

Adams, Charles Francis, Jr., Railroads, Their Origin and Problems. New York, 1887. (From the estate of Robert D. Jenks.)
Barclay, Andrew, Sons & Company, Ltd., General Catalogue of Winding Engines. Caledonia Works, Kilmarnock, Scotland, no date. (From the Company.)
Barry, John Wolfe, Railway Appliances, A Description of Details of Railway Construction. London, 1893. (From the estate of Robert D. Jenks.)
Bellis, Harry Ellwood, Manual of Traffic Efficiency. Philadelphia, 1916. (From the estate of Robert D. Jenks.)
Biehl Iron Works, Inc., Catalogue G. Reading, Pa., no date. (From the Works.)
Bilton Machine Tool Company, Catalogue. Bridgeport, Conn., no date. (From the Company.)
Block Signal and Train Control Board, Second Annual Report, 1909. Washington, 1909. (From the estate of Robert D. Jenks.)
British Columbia Minister of Mines, Annual Report for the Year ending December 31, 1916. Victoria, 1917. (From the Minister.)

Bureau of Railway Economics, Railway Economics, A Collective Catalogue of Books. Chicago, 1912. (From the estate or Robert D. Jenks.)

Cambridge Bridge Commission, Report upon the Construction of Cambridge Bridge. Boston, 1909. (From the estate of Robert D. Jenks.)

Canada Department of Mines, Mines Branch, Bulletin No. 17, The Value of Peat Fuel for the Generation of Steam, by John Blizzard, B.Sc. Ottawa, 1917. (From the Department.)

Canada Minister of Agriculture, Report of the Experimental Farms for the Year ending March 31, 1916. Ottawa, 1917. (From the Minister.)

Canadian Society of Civil Engineers, Transactions, vol. xxx, part ii, 1916. Montreal, 1917. (From the Society.)

Chicago, Burlington and Quincy Railroad Company, Sixty-third Annual Report, 1916. Chicago, 1917. (From the Company.)

Cleveland, Frederick A., and Fred Wilbur Powell, Railroad Finance. New York, 1912. (From the estate of Robert D. Jenks.)

Daly, H. W., Pack Transportation. Washington, 1908. (From the estate of Robert D. Jenks.)

Denver and Rio Grande Railroad Company, Thirty-first Annual Report, 1916. Denver, 1917. (From the Company.)

Detroit Twist Drill Company, Catalogue No. 18. Detroit, no date. (From the Company.)

Edward Valve and Manufacturing Company, Catalogue No. 6, Valves and Fittings. Chicago, 1917. (From the Company.)

Elliott, W. H., The A, B, C of Railroad Signalling. Chicago, 1909. (From the estate of Robert D. Jenks.)

Engineers' Club of Philadelphia, Directory, 1917. Philadelphia, 1917. (From the Club.)

Gardner Machine Company, Catalogue of Grinding and Polishing Machinery. Beloit, Wis., 1917. (From the Company.)

Gordon, W. J., Our Home Railways, How They Began, and How They are Worked, vols. i and ii. London, 1910. (From the estate of Robert D. Jenks.)

Greenfield Tap and Die Corporation, Booklet, Acorn Dies and Holders. Greenfield, Mass., 1917. (From the Company.)

Hammel Oil Burning Equipment Company, Inc., Catalogue. Providence, R. I., 1917. (From the Company.)

Hine, Charles DeLana, Letters from an Old Railway Official. Chicago, 1904. (From the estate of Robert D. Jenks.)

Hooper, William E., Railroad Accounting. New York, 1915. (From the estate of Robert D. Jenks.)

Hungerford, Edward, The Modern Railroad. Chicago, 1911. (From the Estate of Robert D. Jenks.)

Indiana Department of Geology and Natural Resources, Fortieth Annual Report, 1915. Fort Wayne, State Printers, 1916. (From the Department.)

Kansas State Agricultural College, Experiment Station, Second to Fourth, Sixth to Nineteenth Annual Reports, 1889–1906; Directors'

Report, 1914–1915. Manhattan and Topeka, 1890–1916. (From the Station.)

Lincoln Electric Company, Electric Arc Welding. Cleveland, Ohio, 1917. (From the Company.)

Missouri Bureau of Geology and Mines, Biennial Report of the State Geologist to the Forty-ninth General Assembly, 1917. Rolla, 1917. (From the Bureau.)

New Britain, Conn., Board of Water Commissioners, Sixtieth Annual Report. New Britain, 1917. (From the Board.)

Nichols, William, Train Operation. Rochester, N. Y., 1916. (From the estate of Robert D. Jenks.)

Ohio Engineering Society, Proceedings of the Thirty-eighth Annual Meeting. Norwalk, 1917. (From the Society.)

Old Colony Railroad Company, Fifty-second and Fifty-third Annual Reports, 1915–1916. Boston, 1915–1916. (From the Company.)

Pearson, Henry Greenleaf, An American Railroad Builder, John Murray Forbes. Boston, 1911. (From the estate of Robert D. Jenks.)

Pendleton, John, Our Railways, Their Origin, Development, Incident, and Romance, vols. i and ii. London, 1894. (From the estate of Robert D. Jenks.)

Pennsylvania Department of Labor and Industry, Safety Standards of the Industrial Board, Electric Code. Harrisburg, 1916. (From the Department.)

Pennsylvania Railroad System, Information, vols. ii and iii, 1914–1915. Philadelphia, 1914–1915. (From the estate of Robert D. Jenks.)

Rugby (England) Engineering Society, Proceedings, vol. xii, 1914–1915. Rugby, no date. (From the Society.)

Sayings and Writings about the Railways, by Those Who Have Managed them and Those Who Have Studied their Problems. New York, *Railway Age Gazette*, 1913. (From the estate of Robert D. Jenks.)

Schmidt, Edward C., Freight Train Resistance, Its Relation to Car Weight. University of Illinois Bulletin No. 43. Urbana, 1910. (From the estate of Robert D. Jenks.)

Shoe and Leather Reporter, Annual. New York, 1907. (From the Publishers.)

St. Louis-San Francisco Railway Company, Report as of December 31, 1916. St. Louis, Mo., 1916. (From the Company.)

St. Louis Water Commissioner, Annual Report for the Year ending April 1, 1917. St. Louis, Mo., 1917. (From the Water Commissioner.)

Strong, Sturgis & Co., Seventy Years of America's Greatest Railroad, The Pennsylvania, 1846–1916. New York, 1916. (From the estate of Robert D. Jenks.)

University of Louisville, Catalogue, 1917–1918. Louisville, Ky., 1917. (From the University.)

University of Oklahoma, General Catalogue, 1916–1917. Norman, 1917. (From the University.)

University of Tennessee, Register, 1916–1917. Knoxville, 1917. (From the University.)

University of Texas, Catalogue, 1916–1917. Austin, 1917. (From the University.)

U. S. Department of Commerce, Bureau of Foreign and Domestic Commerce, Statistical Abstract of the United States, 1916. Washington, 1917. (From the Department.)

U. S. Department of Commerce, Bureau of the Census, Abstract of the Census of Manufactures, 1914; Mortality Statistics, 1915, Sixteenth Annual Report. Washington, 1917. (From the Bureau.)

U. S. Navy and Marine Corps, Register of the Commissioned and Warrant Officers, January 1, 1917. Washington, 1917. (From the Navy Department.)

Ware Brothers Company, The American Fertilizer Hand Book, Tenth Annual Edition, 1917. Philadelphia, 1917. (From the Company.)

Werner and Pfleiderer Company, Catalogue of Universal Kneading and Mixing Machines. Saginaw, Mich., 1917. (From the Company.)

Western Australia Geological Survey, Bulletin No. 60, General Index to Reports, 1870–1910. Perth, 1916. (From the Survey.)

---

## BOOK NOTICES.

THE ANILINE COLOR, DYESTUFF AND CHEMICAL CONDITIONS from August 1, 1914, to April 1, 1917. Compiled by I. F. Stone. New York, The National Aniline and Chemical Company, 1917. 224 pages, 8vo.

In the great events of life, the attention of mankind is often focussed on incidents that are really minor in their significance, but which are either at once typical and easily understood, or by some combination of circumstances brought at once into the spotlight, and the first impression is never wholly lost.

The general war that broke out in the summer of 1914 produced almost immediately intense reactions in the industrial and commercial operations of the United States, and, so far as general public discussion was concerned, perhaps no more intense interest was awakened than in the coal-tar color manufacture. Yet the total value of synthetic colors imported into the United States in a normal year is only about nine millions of dollars, and one firm of chain stores in this country sells ten million dollars' worth of candy alone, and one automobile factory sells over one hundred million dollars' worth of its products in the same period.

The book before us is a very valuable contribution to the problem of establishing the tar industries in this country upon a basis which will prevent their being upset by competition from any other country. That these industries would be so established seems to be undeniable. It is not for colors alone. These have formed the subject of the most active discussion since the breaking out of the war, but, as noted above, the total consumption in this country does not present figures com-

parable with many other industries. It is the utilization of coal-tar (and, incidentally, some other tars) for the manufacture of a variety of substances necessary in both peace and war. The modern high explosives belong to this class, and a country which is equipped to make the colors is equipped to make most of the other tar products. No great nation can afford to leave these manufactures in the hands of another great nation that may become suddenly hostile. It can scarcely be doubted that when the nations lay down their arms an economic war, fought with tariffs, trade agreements, combinations, and other methods to control competition, will break out, and those who desire to know the facts of the case will need to read this work carefully, and also a work recently published, "The British Coal-Tar Industry: Its Origin, Development, and Decline."

The National Aniline and Chemical Company, publisher of the work under consideration, is a combination of several of the most prominent and best-equipped establishments engaged in the manufacture of tar products. Its organization is a step in the right direction, for the complex procedures of manufacture and the intricate problems of marketing can best be solved by a company which can afford to employ a large staff of experts in both scientific and business departments.

HENRY LEFFMANN.

## PUBLICATIONS RECEIVED.

*Allen's Commercial Organic Analysis:* A Treatise on the Properties, Modes of Assaying, and Proximate Analytical Examination of the Various Organic Chemicals and Products Employed in the Arts, Manufactures, Medicine, etc. Fourth edition, vol. 9, edited by W. A. Davis, B.Sc., A.C.G.I. 836 pages, illustrations, 8vo. Philadelphia, P. Blakiston's Son & Co., 1917. Price, $5.

*Directions for Designing, Making, and Operating High-pressure Transformers,* by F. E. Austin. Second edition. 46 pages, illustrations, 12mo. Hanover, N. H., Author, 1917. Price, 65 cents.

*Carnegie Institution of Washington:* Researches of the Department of Terrestrial Magnetism, vol. iii, Ocean Magnetic Observations, 1905–1916, and reports on special researches by L. A. Bauer, director, with the collaboration of W. J. Peters, J. A. Fleming, J. P. Ault, and W. F. G. Swann. 447 pages, illustrations, plates, maps, quarto. Washington, Carnegie Institution, 1917.

*Ohio State University,* Congress of Human Engineering, October 26, 27, and 28, 1916. 160 pages, 12mo. Columbus, University, 1917.

*Concrete Ships a Possible Solution of the Shipping Problem.* 35 pages, illustrations, 8vo. Chicago, Portland Cement Association, 1917.

*U. S. Bureau of Mines:* Technical Paper 143, The Ores of Copper, Lead, Gold, and Silver, by Charles H. Fulton. 45 pages, 8vo. Technical Paper 160, Determination of Nitrogen in Substances Used in Explosives, by W. C. Cope and Guy B. Taylor. 46 pages, illustrations, 8vo. Technical Paper 169,

Permissible Explosives Tested Prior to January 1, 1917, by Spencer P. Howell. 19 pages, 8vo. Technical Paper 177, Preparation of Ferro-uranium, by H. W. Gillett and E. L. Mack. 46 pages, illustrations, 8vo. Monthly Statement of Coal-mine Fatalities in the United States, April, 1917. List of Explosives, Lamps, and Motors Tested Prior to May 31, 1917. Compiled by Albert H. Fay. 24 pages, 8vo. Washington, Government Printing Office, 1916–1917.

*U. S. Department of Agriculture:* Bulletin 552, The Seasoning of Wood, by Harold S. Betts, M.E., in charge, Office of Industrial Investigations. 28 pages, illustrations, plates, 8vo. Farmers' Bulletin 805, The Drainage of Irrigated Farms. 31 pages, illustrations, 8vo. Washington, Government Printing Office, 1917.

*Solvay Alkali:* Its Various Forms and Uses, with Notes on Alkalimetry and Chemical and Commercial Tables Conveniently Arranged for the Use of the Consumer. 56 pages, illustrations, 8vo. Syracuse, N. Y. Solvay Process Company, 1916.

---

## ERRATUM.

**MAINTAINING PHOTOGRAPHIC STANDARDS, By Alfred B. Hitchins, Ph.D.,** August, 1917, issue of the JOURNAL, vol. 184, p. 179.

The formula page 194 should read:

$$\gamma\infty = \frac{\gamma 1^2}{2\gamma 1 - \gamma 2} = \frac{\cdot 82^2}{2(\cdot 82) - 1\cdot 36} = \frac{6724}{2800} = 2\cdot 40$$

# CURRENT TOPICS.

**Errors of Registration of Electricity Meters with Varying Loads.** G. W. STUBBINGS. (*The Electrical Review* (London), vol. 81, No. 2067, July 6, 1917.)—The errors of registration of electricity meters over periods during which there is a variation of the current passing are a matter of considerable interest. The problem of obtaining the errors of meters on constant loads is one of great simplicity, but this information gives no *prima facie* indication as to the degree of accuracy with which a meter will register over a period during which the load may vary between wide limits. An interesting case of this question is that of a house in which a moderate load is used for a few hours in the evening, one light through the night, and an occasional use of one light, an electric iron, or some similar device throughout the day. The inaccuracy of the meter on one light may be considerable, but the important point is the extent to which this error will affect the total inaccuracy over such an extended period as one day. The present article is an attempt to investigate this question theoretically, and it may be observed that the results apply equally to cases of rapidly varying loads, such as are taken by certain machines. The investigation is concerned with ampère-hour meters only, and variations of voltage have not, therefore, to be taken into account. The performance of a theoretically accurate meter with varying currents has been previously investigated, and it is now well known that such a meter with eddy-current braking, whether shunted or not, correctly records the total quantity of electricity, notwithstanding any variation of the current.

The case of a meter of the commutator type may first be considered. With such a meter the error is due to an approximately constant frictional torque, and the percentage error curve is of the form $\eta = K - \frac{n}{c}$, $\eta$ being the percentage error, $n$ a constant depending on the frictional torque, $K$ the percentage difference between the correct and ideal speeds of the meter, and $c$ the current passing. Since the meter is inaccurate, the speed of the meter motor will correspond to an inaccurate value of the current, which will be

$$C_m = C\left(1 + \frac{K}{100} - \frac{n}{100C}\right)$$
$$= C + K\frac{C}{100} - \frac{n}{100}$$

This expression refers to instantaneous values of the current, which may be any function of the time. The quantity recorded by

the meter will therefore be obtained by integrating the expression between the limits o and $t'$, $t'$ being the time during which current has been passing.

$$\int_o^{t'} C_m dt = Q + K\frac{Q}{100} - \frac{nt'}{100}$$

$Q$ being the correct quantity. The percentage error will accordingly be $K - \frac{n}{C_a}$, $C_a$ being the average current over the period $t'$. It therefore follows that in the case of a meter with an error curve of the form given the error of registration over a period will be the error at the average current over the same period, whatever be the nature of the variation of the current.

The case of a meter having fluid as well as solid friction may now be considered. With such a meter the error curve will be of the form $\eta = K - \frac{n}{C} - mC$, $m$ being a constant depending upon the magnitude of uncompensated fluid friction. We have therefore:

$$C_m = C + K\frac{C}{100} - \frac{n}{100} - m\frac{C^2}{100}$$

$$\int_o^t C_m dt = Q + K\frac{Q}{100} - \frac{nt'}{100} - \frac{m}{100}\int_o^{t'} C\,dt$$

the percentage error being

$$K - \frac{n}{C_a} - \frac{m}{Q}\int_o^{t'} C^2 dt$$

The portion of the error due to fluid friction is therefore proportional to the ratio of the mean square of the current to the average value of the same, and such value of the fluid friction error will thus always be higher than that at the average load. In the case of most house-service meters, not only is the compensation for fluid friction fairly complete, but the effect of such friction is at the usual loads very small; the value of $K$ is also, owing to the different shape of the error curve, higher than in the case of a meter with solid friction only. It is therefore legitimate to assume that the accuracy of a house-service mercury meter over extended periods will be equal to that of a commutator meter under similar conditions, the circumstance of variation of current only being taken into account. The effect of fluid friction with meters of higher capacities will become more important with varying loads, the magnitude depending upon the nature of the variation. With a load corresponding to $C = C_a(1 + a \sin pt)$, the ratio of the mean square to the mean current will be $C_a\ (1 + \frac{1}{2}a^2)$, and the effect of fluid friction is sensibly increased.

**Power Requirements for Electrochemical Industry.** F. A. LIDBURY. (*Journal of the Western Society of Engineers*, vol. xxii, No. 5, May, 1917.)—The most important single electrochemical industry in point of power requirements, and also in point of value of product, is the aluminum industry. So far as can be ascertained, there is something like 130,000 kilowatts of capacity installed in this country at present for the purpose of making aluminum. Not all of it, however, is in operation, because of conditions, particularly at Niagara Falls. In addition to these there appear to be about 60,000 kilowatts either being installed at present or contemplated. This indicates that the requirements of the aluminum industry alone in this country lie between 100,000 and 200,000 kilowatts. It is not easy to place a definite and arbitrary limit on the rate of growth of that particular industry. The demands seem to be increasing every year, and those demands are not, to a very great extent, war demands, but the increased demand has also come about by the rapid extension of the general uses of aluminum, as, for instance, in the automobile. Its use in the automobile is not only direct, but indirect, and includes the manufacture of certain steels and of steels of a nature which enables small light parts to be used in places demanding great strength in the automobile where a few years ago carbon steel of much greater dimensions had to be used.

Next in point of size, is a group of compounds which cannot very easily be separated from one another—the ferro-alloys, including ferro-silicon, ferro-chromium, ferro-molybdenum, and so on. It is a little difficult to estimate the power requirements of this class. Probably about 100,000 kilowatts would come near the mark. Calcium carbide, with 30,000 kilowatts or more, ranks next. The calcium carbide industry is not growing to-day at the same rate as a few years ago; the use of the carbide for illumination is not so great. On the other hand, the use of acetylene for welding and similar applications is increasing and is to-day, from an engineering point of view, by far the most important use of calcium carbide. Artificial abrasives follow with some 20,000 to 30,000 kilowatts or more, representing the necessities of this country in the manufacture of fused aluminum and silicon carbide, which constitute the basis of all modern grinder work. Then we have the electrolytic alkali business, which gives us caustic soda or caustic potash and chlorine in the form of bleaching powder. Liquid chlorine, or other chlorine products. For these, 30,000 kilowatts would be a reasonable figure to take for the requirements of the country.

The manufacture of chlorates, which are used in the match industry, in textiles, for the manufacture of oxygen, and in certain chemical operations, may be charged with 10,000 kilowatts. Again, sodium, which, of course, is not much used in its original form, but from which is made sodium peroxide, used in the textile industries as a bleaching agent, and is still more important as a starting point in the manufacture of sodium cyanide, will consume perhaps

15,000 kilowatts. There are also a number of minor articles, such as phosphorus, carbon bisulphide, and other products of the electric furnace or of electrolytic processes, which might include 1000 or 2000 kilowatts each. If the really small processes were considered, there are numerous little units working all over the country on numerous minor branches of electrolytic work which may take anywhere from a few kilowatts up to a few hundred.

**Performance of Uniflow Engine in Steel Mill.** ANON. (*Electrical World*, vol. 70, No. 6, p. 248, August 11, 1917.)—After sixteen months' service a uniflow engine installed in the steel plant of the L. F. Shoemaker Company, at Pottstown, Pa., was tested by the engineers of the steel company and showed very high economy, especially at small loads. The uniflow type of reciprocating engine is especially designed to maintain a steady temperature gradient in the cylinder and to operate at low constant losses, and, by means of an unusually simple valve gear, over a considerable range of load.

The engine which was tested is an Ames-Stumpf uniflow engine having a 19-inch diameter cylinder with 24-inch stroke. The engine is direct-connected with a 200-kilowatt, 250-volt, direct-current Crocker-Wheeler generator, which furnishes energy for electric cranes, heavy punches, shears, and general motor loads, and, in addition, all energy for the entire lighting system. The load is extremely variable, there being frequent flash-load fluctuations from one-half load to 25 per cent. overload. The unit operates at 200 r. p. m. with a pressure at the throttle vale ranging from 135 pounds to 150 pounds, with practically uniform vacuum, and is rated at 320 indicated horsepower with 150 pounds pressure, cutting off at one-fifth of the stroke.

The test is especially striking because it was made on an engine which had been working for many months in a steel mill. The vacuum was not particularly good, only 26 inches, and the running conditions for efficiency none the best. Considering all the conditions, the results were highly satisfactory for a simple condensing engine working over a wide range of power. Particularly noteworthy is the exceptionally uniform efficiency obtained through a range varying from quarter load to one and a quarter times full load, the variation in efficiency between these limits being approximately 10 per cent. The average consumption of dry steam per indicated horsepower at full load was down to the very creditable figure of 15 pounds, particularly as this result was a little better than that obtained before a forced run of sixteen months, giving the equivalent of two and a half years' operation on an ordinary ten-hour-a-day basis. The results show plainly that the development of new ideas in engine construction may well lead to real advances, despite the common belief that the reciprocating engine has reached about its ultimate development.

**A Ship with No Reciprocating Machinery.** ANON. (*Scientific American*, vol. cxvii, No. 5, p. 91, August 4, 1917.)—Machinery, just like living things, is undergoing a constant process of evolution. Types arise, become dominant, and then tend to disappear before the advance of newer and better adapted types. Though during the progress of one of these cycles it is generally difficult to determine just what is occurring, we appear to be witnessing a most important one to-day in the gradual conquest of the once dominant reciprocating machine by the rotary type. Thus, the turbine is threatening to displace the engine; the centrifugal pump, the piston pump; the electric locomotive, with its rotary motors, the steam locomotive; and others, cases of the same kind can be cited.

In this connection a tank steamer, now under construction in one of the Delaware River shipyards, is of interest because it is believed to be the first ship to be built without reciprocating apparatus of any kind in its engine-room. Its power plant consists of a low- and a high-pressure turbine geared to a single propeller, a surface condenser with a centrifugal pump driven by a turbine, two centrifugal hotwell pumps also driven by a turbine, and a rotary oil pump for the turbines and gears driven from the main gears.

None of this machinery is novel in principle or application; it merely happens that this is the first time that rotary machinery has been used consistently throughout a ship, thus marking definitely an epoch in the history of shipbuilding.

Undoubtedly the most interesting feature of the machinery itself is the use of a hydraulic dynamometer to measure accurately the total power developed by the turbines. The two turbines are connected to the propeller shaft by two sets of Westinghouse reduction gears, which permit the 3600-r. p. m. turbines to drive the propeller at 70 r. p. m. The dynamometer is incorporated in the pinion frames of the first gear, and its principle is as follows: The pinions and gears run immersed in oil and act as pumps, causing a considerable flow of oil under high pressure to the reservoir. The frames carrying the pinions of the first gears, while normally bolted securely in place, can be released and are so arranged that they will actually float on the stream of oil flowing from the pinions. The pressure of this oil represents the total pressure on the teeth of the pinion plus the weight of the pinion and frame. Therefore, for the gauge pressure of the oil (corrected from the frame and pinion weight) and the revolutions per minute, can be obtained the power transmitted, the sum of the power of both gears giving the total power delivered to the propeller.

**Whale Meat as a Solution of the High Cost of Living.** ANON. (*Scientific American*, vol. cxvii, No. 5, p. 92, August 4, 1917.)—The Bureau of Fisheries, Department of Commerce, has for some time, in correspondence and in personal interviews, been advocating the use of the meat of whales, porpoises, dolphins, and other cetaceans for human food.

Whales and porpoises are mammals, like cattle and sheep, and their flesh is "meat" and not "fish." In texture and appearance it resembles beef, though the color is darker red, and the flavor is closer to that of meat than to any other. It is devoid of all fishy taste. It is likely that it will soon be obtainable fresh, corned, and canned, and it is recommended to those who have the opportunity to purchase it.

Whales are taken at several shore stations on the Pacific coast, where their blubber is rendered for oil and their bones and flesh used to some extent for fertilizer, while their skins appear to be adapted to tanning into leather. These stations take a considerable number of these animals, each furnishing about five tons of excellent meat.

Porpoises are abundant on all our coasts, and there is a regular fishery for them at Cape Hatteras, where they are valued principally for their oil and to some extent for their hides.

During May an enterprising whaling company placed fresh whale meat on the market in Seattle, Wash., and Portland, Ore. The product met with a ready sale at 10 cents a pound, and was immediately placed on the menus of the hotels and restaurants under its proper name.

**Extracting Alcohol from Garbage.** ANON. (*Engineering News-Record*, vol. 78, No. 11, p. 534, June 14, 1917.)—Conserving the food supply of the country by turning city garbage into alcohol instead of using grain or potatoes for the purpose is a promising possibility established by carefully conducted experiments reported from the garbage-reduction plant of Columbus, Ohio. The experiments show that one ton of Columbus green garbage will yield 4.8 gallons of 95 per cent. alcohol of satisfactory quality. Estimates indicate that a $36,000 plant would produce from the 20,000 tons of garbage treated annually at the reduction works a total of 96,000 gallons of alcohol, giving a profit of 42 cents per gallon at war-time prices, or 30.5 cents under normal conditions. A year's garbage, the tests indicate, would yield as much alcohol as could be produced from 33,600 bushels of shelled corn, 39,529 bushels of wheat, or 110,344 bushels of potatoes.

The process is covered by United States Patent No. 1,114,017, granted to Dr. J. J. Morgan, 29 East Madison street, Chicago, Ill. In essence the process consists in extracting grease from garbage by cooking with sulphuric acid and steam, thereby converting the starch and allied products to dextrose; separating the grease from the tank liquor; neutralizing the acid sufficiently to allow fermentation; fermenting the liquor with yeast, thereby converting the dextrose to alcohol, and then recovering the alcohol by distillation.

The cost and profit figures relate to alcohol production alone; that is, they do not take into account the costs of the finishing process for grease and tankage. The insufficient tests showed lower

yields of each than in ordinary garbage-reduction operations; but it was thought that by careful manipulation the tankage loss could be reduced to a small amount, if not eliminated, and that the grease produced would not be reduced either in quality or quantity.

**The Nernst Vapor Lamps.** ANON. (*The Electrician*, vol. lxxix, No. 10, June 8, 1917.)—Prof. W. Nernst describes a vapor lamp in German patents Nos. 288,228 and 288,229 which is somewhat similar to Darrah's lamp and is a decided improvement from the point of view of efficiency. The Nernst lamp rests on the phenomena which are observed when an arc passes between carbon electrodes in an atmosphere of zinc chloride or zinc bromide. These phenomena are analogous to those observed in the vapor of mercury and other metals. If the pressure of the zinc chloride vapor is too low, the light is dull, but at higher pressures (*e.g.*, at atmospheric pressure) the arc is sharp and bright. The chlorides of aluminum and titanium behave similarly to zinc chloride, titanium chloride being especially suitable for the object in view. The efficiency of these chloride lamps is about the same as in the high-pressure mercury vapor lamps.

According to one patent, the lamp includes a spherical bulb which contains the two carbons. The upper electrode is controlled by a solenoid suitably protected from the effects of the vapor. The lower part of the spherical bulb ends in a short, closed tubular connection which contains the salt to be vaporized. The volatilization is effected by an external source of heat; for this purpose the series resistance to which the lamp is connected may be suitably used.

In a second patent Nernst describes a vapor lamp in which the main conducting medium is mercury vapor; a suitable salt is added to give a better color to the light. The principle of the lamp consists in adding a line spectrum to that of the mercury vapor; in this way a white light is produced. Mercury vapor, however, has the property of continually removing any foreign substances. It is therefore possible to introduce the coloring matter continuously, if such substances are used as fuse at the temperature of the mercury vapor lamp. The substances thus continuously volatilize with the mercury, subsequently condensing and flowing back into the circuit in order to repeat the cycle of operations. Small conical glass protectors fused into the vessel surround the carbon and prevent the condensed drops of mercury and salt from reaching the arc. An especially suitable salt mixture for these lamps is said to consist of 70 per cent. zinc chloride, 15 per cent. calcium chloride, 5 per cent. thallium chloride, 5 per cent. lithium chloride, and 5 per cent. cæsium chloride. A lamp of this kind without a series resistance gives a light of 3000 hefner candle-power on 120 volts; it takes 4 ampères, and therefore has an efficiency of 0.16 watt per hefner candle-power, which is a considerable improvement on other electric lamps.

**Leeds & Northrup Optical Pyrometer.** ANON. (*Power,* vol. 46, No. 5, p. 149, July 31, 1917.)—Measurements by radiation can be carried out at a distance, once the laws of connecting temperature of radiating body and intensity of radiation have been determined, and the radiation receiving and measuring part need not be heated to the temperature of the radiating body, nor even near that temperature. Pyrometers utilizing radiation are divided into two classes —those which measure as heat energy the total radiation falling upon the receiving part of the instrument, and those, known as optical pyrometers, which are based on the fact that the luminous radiation or light varies in a definite manner as the temperature of the hot body changes.

The greatest success has been attained by separating out one kind or wave-length of radiation, usually that which excites the sensation of red, and comparing the intensity of this one-color light with the intensity of the light of the same color emitted by a standard source of light. The eye is very sensitive when comparing the brightness of two surfaces when one is superposed upon the other, and, after having arranged to have light from the hot body and light from the standard of comparison viewed in this relation, they can be made equal, either by varying the amount of light received from the incandescent object or by varying the intensity of the standard of comparison.

The latter method—that is, variation of the standard of comparison—is used by the United States Bureau of Standards. The Leeds & Northrup Company, of Philadelphia, under the fundamental Morse patents, has lately developed this type of optical pyrometer. The instrument, which is essentially a monocular telescope, is suitable for measuring from dull red (about 1100° F.) up to the highest known temperature. Between the eyepiece and the objective a tungsten lamp filament is located in the plane containing the point to which rays from the hot body are brought to a focus. By means of the eyepiece, the observer views the incandescent filament, which appears to lie upon the image, just as the cross-hairs of a surveyor's telescope appear upon the distant object viewed. By means of a rheostat in a case slung about the neck, the case also containing a storage battery and milliammeter, the current through the lamp is adjusted until the brightness of the filament and that of the image are equal, and the temperature is determined by referring the milliammeter reading to a calibration curve. In observing bodies at such high temperatures as 2500° to 10,000° F., the light received would be too blinding for direct observation, even through the red glass with which the eyepiece is provided, and also beyond the capacity of the lamp. Therefore a screen is used, placed between the lens and the image so that it reduces the light from the hot body but not that of the filament. This screen can be thrown in or out of the field of view when required, the readings being referred to a different calibration when the screen is in use.

**A New Permanent Magnet Steel.** ANON. (*Scientific American*, vol. cxvii, No. 6, p. 107, August 11, 1917.)—A new steel of considerable importance has been made in the United States for the last year or so, directly the outcome of war conditions. It is a new permanent magnet steel, a substitute for the older steel; it is known as tungsten magnet steel, used exclusively for this purpose before the war. Not long after the war began and the price of tungsten advanced, efforts were made to find a steel that would be cheaper and also as efficient as the permanent magnet steel then being used, containing tungsten varying in amount from 5 to 10 per cent. and sometimes even up to 25 per cent. The demand was insistent from both magneto makers and electric companies making electric meters, because the tungsten magnet steel was reaching prohibitive prices. It was even stated that automobile makers were substituting batteries for magnetos because American steel makers could not make as good magnet steel as foreigners.

The new steel, which is reported to be not less than 90 per cent. as efficient as the old permanent magnet steel, is a 0.90 per cent. carbon steel containing about 2 per cent. of chromium, and is now being made in electric furnaces in this country and extensively used by many consumers. This new type of steel is based on investigations made by Dr. John A. Matthews, of Syracuse, N. Y., and published by the American Society for Testing Materials about three years ago, in which it was pointed out for the first time that certain types of steels are better magnetically when quenched in water. This statement was contrary to all previous ideas regarding the hardening of steel for permanent magnets.

Magnetically this new chromium steel is equal to tungsten magnet steel in permanence and somewhat lower in residual density. Users have found it possible to substitute this steel for the older steel without making any change whatever in their windings or in the cross-sections of the magnets used. Practically chrome magnet steel, as the new steel is called, is not equal to the tungsten magnet steel, because it requires oil hardening and also because chrome steel in its natural state is much harder to drill or machine and the steel itself must be handled with greater care and uniformity in heat treatment than is necessary with tungsten steel. A large electric manufacturing company has been using this material for permanent magnets. By close coöperation with the manufacturers of the steel and careful development of treatment processes they have been able to obtain entirely satisfactory results.

**Voltage Standardization.** M. D. COOPER. (*General Electric Review*, vol. xx, No. 7, p. 564, July, 1917.)—One of the fundamental factors of our present-day civilization is standardization. In fact, it may be said that our entire economic and commercial development has been brought about by standardization or coöperation in the use of standardized measures of quantity and value,

standard methods of action, etc. The electrical industry of this country has grown to its present importance and high state of development very largely by reason of the high degree to which electrical apparatus, appliances, material, and methods have been standardized. Although the electrical industry is outranked by no other industry in thoroughness of standardization, yet there is one feature that shows a considerable lack of standardization; namely, voltage distribution. There is, of course, a standardization of ranges of voltage, such as 105 to 125, 220 to 250, etc., but in any one of these ranges there is no commonly accepted standardization upon certain definite values. If voltage standardization upon a very few values could be brought about, a very great benefit would accrue to the electrical industry.

Since the incandescent lamp requires the closest voltage selection of any piece of current-consuming apparatus, the conditions surrounding the manufacture of incandescent lamps have always had a very large part to play in the selection of operating voltages for lighting companies. At an early period of the industry, practically all central stations were operated at either 100, 104, or 110 volts. In time the desire for a wider distribution and more economical use of copper led the lighting companies to seek higher voltages than 110, with the result that ultimately the demand for lamps was spread over a range from 100 to 130 volts, although now the greater proportion of the demand lies between 110 and 125 volts. With the introduction of the tungsten filament lamp there has been a decreasing necessity for a wide range of operating voltages, because lamp manufacturers have continuously been able to make their lamps closer and closer to the predetermined voltage of design. At the present time the processes of manufacture are so far developed that Mazda lamps can be made true to voltage within commercial limits. As the influence of the manufacturers has been withdrawn from maintaining a diversity of demand for various voltages, the trade has shown an evident tendency toward standardization of certain voltages. The tendency now is toward a universal standardization on 110, 115, and 120 volts.

**The Detinning Industry.** ANON. (*Reactions*, Second Quarter, 1917, vol. 10, No. 2, p. 30.)—Before the outbreak of the war, the production of tin plate in England was 700,000 tons per year, while in the United States the yearly output was over 1,000,000 tons, and at present the production is estimated at 1,300,000 tons. As the industry grew to large proportions, the disposal of the clippings and other scrap, which accumulate in large quantities, became an important problem, because, unless the tin could be removed from the iron, the scrap could not be puddled, or remelted in melting furnaces. This at first did not appear to be very difficult, and it appealed to the inventor, as the can factories were glad to give away their tin scrap and even to pay cartage simply to be rid of it.

Promising as the problem appeared, it required many decades of study and experiment before a profitable method was developed.

All the processes which have been actually operated may be divided into three general classes: the mechanical process, the chemical process, and the electrochemical process. In the mechanical process the effort was made to separate the tin from the iron by means of heat, and later by refrigeration. The method was not practical, however, because it was not possible to obtain a thorough separation of the tin from the iron. Most of the chemical and electrochemical processes were also failures, because the acids used would not dissolve the tin sufficiently and left a considerable amount adhering to the iron. It was also found in many cases that the chemicals used were too expensive to make the process an economical one. Three processes, however, have operated successfully, more or less in competition with each other for the last forty years. These three processes are the electrolytic alkali process, the chlorine process, and the alkali chemical process. Despite its apparent simplicity, the electrolytic alkali process was supplanted by the early chlorine process

When dry chlorine is brought into contact with tin clippings, the chlorine and tin will combine, and the anhydrous tetrachloride of tin which is formed will drip off. As chlorine at low temperature does not attack iron, the process is apparently very simple. Notwithstanding its seeming simplicity, it required a number of years to develop the process in such a way that it could be used commercially. In 1907 the chlorine process gained real importance in the hands of the Goldschmidt Company, which abandoned the electrolytic method which it had developed in favor of the chlorine process. Since then it has grown very rapidly, and to-day there are larger quantities of tin scrap and old tin cans detinned with the chlorine process than by all the other processes combined.

Another process is detinning by means of alkalies, either alone or in combination with oxidizers. This method was practised at an early stage of the industry, but it did not always remove a sufficient amount of tin, with the result that a considerable part was left on the iron. It is only within recent years that this process, using alkali and saltpetre, has been satisfactorily developed, and the results compare in every respect with the product of the chlorine process. The Goldschmidt Detinning Company uses this process as well as the chlorine process in its various plants, and its output, in addition to detinned scrap, comprises large amounts of tetrachloride of tin and pig tin of a purity which in every respect is the equal of Straits tin. The company recovers every year the equivalent of almost 2000 gross tons of metallic tin.

**Metallurgy of Ferrochromium.** R. J. ANDERSON. (*Iron Trade Review*, vol. lxi, No. 1, p. 75, July 12, 1917.)—Ferrochromium, like ferrosilicon, was one of the pioneer alloys made in the electric fur-

nace at the time when this appliance was first used for the manufacture of the ferro-products. The use of chromium in alloy steels has markedly increased, and its employment promises to further increase on account of the special properties it confers upon the metal. Chromium steels are well adapted for use in the manufacture of armor plate and for armor-piercing projectiles, as well as for automobile parts, and in other cases where great hardness and high tensile strength are desired. In combination with nickel, chromium forms the now well-known chrome-nickel steel of the trade. Recently it has been employed with tungsten for magnet purposes.

Prior to the introduction of the high-temperature electric-melting furnace, the manufacture of ferrochromium was performed almost entirely in the blast-furnace stack, although a smaller amount was made in the crucible. Crucible manufacture gives high-tenor alloys, but several concomitant disadvantages are present. Only small charges can be fired at a time, the crucible cost is high, as special and expensive pots are required, and the alloys, though rich in chromium, are also comparatively high in impurities. The product is therefore not always satisfactory. For commercial purposes the electric furnace affords a satisfactory appliance in which alloys high in chromium tenor and low in impurities can be smelted. The large quantities demanded in steel metallurgy for chromium steel production are now made in the electric furnace in the United States, Germany, and elsewhere. The modern ferrochromium is a high-percentage alloy containing 60 per cent. chromium or more, and the physical properties are directly a function of the amount of carbon present.

Only a small amount of ferrochromium is made in the blast furnace at the present writing, for the reason that the electric furnace is more efficient where the power cost is low, and, further, the electric furnace turns out a better product. When ferrochromium is made in the blast furnace it requires a heavy fuel consumption for its successful manufacture; about three tons of fuel per ton of 40 per cent. alloy are used. The modern method of making ferrochromium is in the electric furnace, although a lesser quantity is produced by the thermit method. Generally speaking, the iron-chromium alloy produced in the electric furnace analyzes about 60 to 65 per cent. chromium and 5 to 9 per cent. carbon.

PRESS OF
J. B. LIPPINCOTT COMPANY
PHILADELPHIA